Jarvis

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BY

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BIOGRAPHICAL SKETCH.

Royal Preston Jarvis was born in Riverton, Iowa, Feb. 13, 875. In the spring of 1880 he moved with his parents to the State of Colorado, and continued to reside in that State until 1900, with the exception of a few brief visits East. His early education was obtained in the schools of Crested Butte, Colo., graduating from the Gunnison High School in 1893. In the fall of this year he matriculated at the Colorado School of Mines, graduating therefrom with his class in 1897. Later he accepted the position of assayer in the works of the Bimetallic Smelting Co., of Leadville, Colo., and remained in the employ of this company until the plant was permanently closed in 1900. In the fall of 1900 he entered Columbia University a graduate student, and attended most of the session of 1900-01. In the fall of 1901 he was appointed chemist to the Cia. Metalurgica de Torreon, Torreon, Mexico. He remained with this company until the spring of 1903, finally filling the position of Assistant Superintendent of the plant. Mr. Jarvis was appointed to the chair of Mining and Metallurgy in the Washington State College in the fall of 1903, which position he occupied for three years. In the fall of 1906 he resumed his work in Columbia University, and received the degree of A.M. in 1907. He was appointed in the spring of 1907 to fill the newly-created chair of Mining and Metallurgy in the University of Tennessee at Knoxville.

SUBJECT TO REVISION.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Investigation on Jigging.*

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I. Introduction.

The jig, in one form or another, continues to hold a leading place among the machines designed to separate two or more

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minerals of different specific gravities. It is simple in construction, easily operated, capable of treating large quantities in a short time, and highly efficient under various conditions.

The question, whether the material to be jigged has first been sized, determines the two principal methods of jigging. Jigging preceded by close sizing, generally known as the Continental or German system, involves a more or less elaborate series of screens or trommels, with attendant cost for installation, operation, and repairs. Jigging without sizing, known as the English system, is, according to Munroe,[1] "a development of the hand-jigging formerly employed in Cornwall . . . and introduced by English miners to this country." In its simplest form, the method consists in jigging an ore-mixture previously crushed to some maximum size (although, in some cases, even this preliminary is omitted) on a relatively coarse sieve, and then jigging again on a finer sieve, the material passing through the first sieve and bedding. While many modifications have been necessary to adapt it for use in mills of large capacity, where hand-work was necessarily replaced by machines, the principle remains the same; the fact that the English system has been successfully employed, both in this country and abroad, is well known; and arguments have been made for its efficiency and applicability in a wider sphere than it has occupied hitherto.

II. Review of Previous Investigations.

The fact that treating a mixture of minerals under jigging conditions increased the amount of mineral saved; or, as Professor Richards aptly terms it, "the extra jig-catch," has long been known. To account for this fact a number of theories have been proposed. The work of Rittinger[2] in this field has, for many years, been a classic in the literature of ore-dressing. For the purposes of my present paper, however, the work of two American investigators, Prof. H. S. Munroe and Prof. R. H. Richards, is chiefly concerned.

Professor Munroe has given the results of an elaborate series of experiments,[3] and his deductions, based largely on theoretical grounds, of this work. After reviewing briefly the two systems of jigging, followed by a discussion of Rittinger's formulas and

[1] *Trans.*, xvii., 637 (1888–9).
[2] *Aufbereitungskunde*, pp. 165, 270.
[3] *Trans.*, xvii., 657 (1888–9).

the derivation of them, and after a careful study of the behavior of grains (usually shot) in a tube *en masse*, acted upon by a rising current of water, he is led to conclude that the interstitial currents play a very important rôle, and are responsible for the high ratios of concentration obtainable in the English system of jigging. Since his conclusions bear directly upon the present investigation, they are given in full, as follows:

"1. Bodies falling through water in a tube do not attain as high a velocity as in falling through the same medium in large vessels.

"2. The falling velocity is but little affected when the diameter of the body is less than one-tenth that of the tube.

"3. The falling velocity is the more retarded as the diameter of the body approximates that of the tube.

"4. A sphere four-tenths the size of the tube will develop the greatest falling velocity, and will require a current of maximum velocity to support or raise it.

"5. Grains falling *en masse* are really moving in confined channels, and follow the law of the movement of bodies in tubes. The falling velocity, and the velocity of the current necessary to support or raise a mass of grains, increase and diminish with the distance apart of the grains.

"6. The diameter of the channel in which the single grain moves equals the cube root of the volume of the grain with its proportion of the interstitial space. . . .

"7. In a mass of grains of different sizes, the large grains move relatively in smaller channels than the small grains. The ratio of the diameters of equal-falling grains of quartz and galena, under such conditions, is 31 to 1, instead of 4 to 1, which latter ratio holds good for free-falling grains only.

"8. The formulæ for grains moving in tubes, when applied as above to grains moving *en masse,* enable us to compute the velocity of jig-currents and thus determine the proper length and number of strokes of the jig-piston. The old formulæ gave results many times too large.

"9. *The present investigation demonstrates that close sizing is not necessary for the separation of different minerals by jigging, unless the difference in specific gravity is small.* . . .

"10. Downward currents are apparently necessary to success in jigging through a bed. This requires confirmation by experiments on a larger scale.

"11. Very fine material, less than $\frac{1}{10}$ millimeter in diameter, can be treated successfully on jigs, *if treated with coarse stuff*, the concentration taking place in the small interstitial channels between the grains forming the mineral bed. *For the treatment of fine stuff on jigs, close sizing is a positive disadvantage.* Jigs work well on mixed stuff, and very badly on fine stuff alone. Stuff less than four-tenths the size of the smallest interstitial channels cannot be treated successfully in this way.

"12 The size of the mesh of the jig-sieve has a very important influence, and must be proportioned to the work to be done.

"13. The English method of jigging without sizing, except possibly so far as is necessary to remove the very finest slimes, has many advantages, and should be more generally adopted."

Professor Richards,[4] in a very careful and elaborate investiga-

[4] *Trans.*, xxiv., p. 409 (1894).

tion on the question of jigging relatively small sizes, treats it under four heads: (1) the law of equal-settling particles; (2) the law of interstitial currents; (3) the law of acceleration; and (4) the law of suction. These four laws are supposed to govern all jigging operations. Practically, Professor Richards's full conclusions are: [5]

"The two chief reactions of jigging are pulsion and suction.

"The effect of pulsion depends upon the laws of equal-settling particles, interstitial currents, and, possibly, also of acceleration. The chief function of pulsion is to save the larger grains of the heavier mineral, or the grains which settle faster and farther than the waste.

"The effect of suction depends upon the interstitial factor of the minerals to be separated. . . . If this factor is greater than 3.70, suction will be efficient and rapid. If the factor is less than 3.70, suction will be much hampered and hindered. The use of a long stroke will help to overcome this difficulty. The chief function of suction is to save the particles that are too small to be saved by the laws of equal-settling particles, and of interstitial currents, acting through the pulsion of the jig.

"For jigging mixed sizes, pulsion with full suction should be used.

"For jigging closely-sized products, pulsion with a minimum of suction should be used."

He concludes by saying, in effect:

In jigging minerals having an interstitial factor greater than 3.7, sizing is simply a matter of convenience, although the fine sizes should be removed in some suitable manner. But if the factor is less than 3.7, then the jigging of mixed sizes cannot give a perfect separation, and if this is desired, then close sizing must be adopted, and the closer the sizing the more perfect the jigging. As an expedient, however, there are often cases where a satisfactory separation may be attained without sizing.

The differences in the conclusions of the two investigators above quoted have been chiefly influential in suggesting this present investigation, which was begun in the fall of 1906, and the results of the work done in the Mining Laboratory of the Columbia School of Mines have been embodied in a paper submitted to the Faculty of Pure Science in Columbia University. Since most of the work done then was preliminary to that recently undertaken, I include herewith a *résumé* of my former results and conclusions.

III. Résumé of the Results of Previous Preliminary Work.

In the following investigation an effort was made to determine, among other things: (1) the conditions and laws of

[5] *Trans.*, xxiv., 485 (1894).

hydraulic classification; (2) the conditions and limitations of jigging in the pulsion-jig; (3) the effect of varying the length and number of strokes per minute in the Vezin laboratory-jigs; (4) experiments with a large 5-compartment Harz jig to determine the limits and perfection of separation effected in an ore containing galena and sphalerite with a quartzose gangue.

Considered briefly, the results of these tests, in the above-named order, are:

1. *Hydraulic Classification.*

A number of tests were made with quartz paired with galena, antimony, arsenopyrite, magnetite, sphalerite, etc., in different proportions, and with a velocity varied between wide limits, in order to determine whether a fixed ratio existed as to the diameters of the grains of the two minerals. All tests under this head were made in a Munroe hydraulic laboratory-classifier. Without going into details of the methods, etc., the results indicated that whether or not a more perfect separation was effected in the classifier-tube itself, the manner of drawing off the classified products always resulted in giving a large proportion of mixed products, and after a number of calculations upon different drawings, similar to the manner detailed under the pulsion-jig tests, and described by Professor Richards,[6] proved to my satisfaction that no such ratio existed with classified products under the conditions the above type of classifier was operated and the products removed.

2. *Pulsion-Jig Tests.*

The largest size of Munroe hydraulic classifier was first fitted up in such way that a column of ore 5 to 6 in. long was supported upon a bedding of large grains, and then treated with a pulsating current of water. The tube in which the jigging took place had a diameter of about 1.75 in., and the pulsion was effected by compressing a rubber tube connecting the bottom of the ore-column with a pressure-head of water. The compression of the tube was effected both by mechanical means and by hand, and apparently it made little difference which method was used. The bedding-grains served only to support the ore-column and confine it within the tube; and in

[6] *Op. cit.*, p. 450, *et seq.*

drawing off the products this was always first to be removed. The results of jigging under these conditions and the removal of the jigged product—namely, by allowing the jigged material to subside gradually into a rubber tube connected with the receptacle which supported the bedding, if it may be called such, and which was really the hutch of the jig, were that after drying, screening, weighing, and analyzing the different screen-products from a number of drawings, and finally calculating the ratios between the diameter of the grain of quartz and that of the other mineral paired with it, no such ratio as that given by Richards could be obtained under such conditions, but the tests were in all respects duplicates of the first series run with the classifier operated under the conditions of hydraulic classification.

It was found, however, that if the jigged products were not removed from the jigging-tube as above described, but, instead, a screen attached to the lower end of the jigging-tube, and the mixture of minerals jigged on this screen, and then instead of drawing off the products through the rubber tube at the bottom the entire apparatus was dismantled, and the jigged products removed from the tube by inserting a piston and forcing the ore-column from the bottom of the tube, cutting sections at equal intervals, that approximate concordant results were obtained. These sections, which were cut off at equal intervals, and usually eight or nine in number, were dried, sized on a nest of sieves, weighed, and analyzed. Ratios of diameters were then calculated for some four or five drawings, in which the mixed grains occurred, according to the method described by Richards,[7] which was as follows: The average diameter of the quartz-grains was obtained by multiplying all the quartz-weights in a particular drawing by their diameters, and dividing the sum of the products by the sum of their weights; and similarly for the other mineral paired with it. The average diameter of the quartz-grain thus determined is divided by the average diameter of the grains of the other mineral, and the quotient is the desired ratio. Table I. gives the ratios that were obtained with the pulsion-jig, the material in nearly all cases being sized between 0.15 and 2 mm. For purposes of comparison I have included the ratios obtained by Professor Richards[8] with a

[7] *Trans.*, xxiv., 450 (1894.

[8] *Trans.*, xxiv., 463 (1894).

pointed tube, the results of which he considers to hold true for the pulsion-jig as well.

TABLE I.—*Equal-Settling Ratios of Minerals in Pulsion-Jigs.*

Name and Specific Gravity.		Ratio for Pulsion-Jig.	Richards's Ratio.
Quartz, 2.58 and	Galena, 7.14	5.80	5.842
	Antimony, 6.66	5.20	4.896
	Arsenopyrite, 5.71	4.42	3.737
	Magnetite, 4.76	3.65	not given.
	Sphalerite, 3.70	2.61	2.127

In the tests of Table I., 50 per cent. by volume of each mineral was used. It seems evident, therefore, that under the conditions that exist under the influence of pulsion alone, the free-settling ratios obtained with Rittinger's formula[9] are increased, but by no great amount.

3. *Vezin Laboratory-Jig Tests.*

Without going into the details of construction of this very useful little laboratory-apparatus, suffice it to say that the piston is driven by a variable-speed shaft, with a disk and friction-wheel, and the number of strokes may be varied from 100 to 300 per min., and, with a double eccentric, the length of stroke from 0 to 1.25 in. (31.7 mm.). The box carrying the sieve is attached to the body of the jig by means of clamps, so that, together with the ore and bedding resting on the sieve, it may easily be removed and the contents examined, or another box with its attached sieve substituted. In all tests with the Vezin jig a sieve of 8-mesh (2.2 mm. square hole) was used. The bedding was in most cases sized between the limits of 2.5 and 3.3 mm., and maintained at a thickness of 0.75 in. (19 mm.). The jig was driven from a counter-shaft by an electric motor, so that a uniform speed was secured. The feed in all cases was sized between the limits of 0.10 and 1.9 mm., and the various mixtures were made up by volume to contain 3 of quartz and 1 of the heavier mineral. From 1.6 to 2.0 kg. represented the amount generally employed in each test. After this quantity had been run over the jig it was stopped, the sieve-box removed, the contents placed in a large pan and dried, the hutch-work

[9] *Trans.*, xvii., 639 (1888–9; *ibid.*, xxiv., 411 (1894).

drawn off, the water decanted and treated in the same way, and finally the tailings were freed as far as possible from water and dried. The three products were then sized separately on a nest of sieves, each size weighed and analyzed, the material being subsequently used again for another test.

It is evident that in so simple a machine as the Vezin jig there are a number of factors that may be made either constant or variable. Thus the length of stroke and number per min. are easily varied, or may be kept constant; the size of the grains constituting the bed, and its thickness, may be varied within limits, although this is likely to vary with other factors, especially the piston-speed; then the quantities of water used on the piston side, with the feed and the amount discharged from the hutch, as well as the rate of feed, may also be varied. In these tests the length and number of strokes were the principal variables, and also the amount of suction, of which there are a number of degrees, limited as follows:

(A) Full suction. In which the hutch-spigot is fully open, and the water thus discharged is supplied entirely by increasing the amount added with the feed, and, if possible, cutting down the amount supplied to the piston side.

(B) Part suction. In which the hutch-spigot is not fully open, and does not discharge a quantity equal to the extra amount added with the feed.

(C) Balanced suction. In balanced suction the hutch-spigot is closed and the feed-water and piston-water are equal; or the hutch-spigot is partly or fully open, and the amount thus discharged is supplied entirely from the piston side.

The results obtained indicate the following conclusions:

A. *Suction.*—With full suction, (A), the bed was not mobile, and after a few minutes' feeding the jig was very badly choked and little or nothing passed into the hutch. After trying a few tests with the same bad results, full suction was considered impracticable. In the case of part suction, (B), the mobility of the bed was decreased in proportion to the amount of suction, and with it a decrease in the amount of coarse mineral passing into the hutch, but with a corresponding increase in the amount of fine material without a noticeable enrichment. The best results were obtained with balanced suction, having the spigot completely closed, although the results with the

spigot partly or fully open did not differ materially from those of full suction (A).

B. *Feed-Water and Rate of Feed.*—These factors were kept as nearly constant as possible, and the effect of varying them was not considered.

C. *Filter-Bed.*—The thickness and the size of the filter-bed, also, were made a constant. It was found, however, that the shape of the grains of the bedding does influence the ease and rapidity with which the mineral passes into the hutch. Thus with antimony and arsenopyrite, both of which break into long, pencil-shaped grains, the sieve became quickly blinded, which interfered with the free passage of grains below, and required a long, heavy stroke to dislodge them.

D. *Length and Number of Strokes.*—The results of the tests seemed to show that the character of the separation is not directly dependent upon absolute piston-speed, but that the quick, short stroke was more efficient, and resulted in a cleaner hutch-product, and relatively more of it, than a longer stroke of less frequency, but of the same piston-speed.

E. *Concentration.*—If the diameters of the grains of the heavy mineral jigged, and of the bedding-grains (and therefore the diameter of the sieve-hole), do not differ by any large amount, a clean separation can easily be made. With an increase in these ratios, perfect separation is impossible. Stated in other words, with bedding of a definite size, and hence a fixed sieve-aperture, the finer the grain the more difficult is its separation on the jig.

F. *Specific Gravity.*—Within rather wide limits, the difference in the specific gravity of the heavier mineral paired with quartz did not influence greatly the ease with which it could be separated, or a good concentration attained.

4. *Experiments with a 5-Sieve Harz Jig.*

Two runs were made as nearly as possible under practical conditions to determine to what extent the conclusions derived from the Vezin-jig tests were applicable to an ordinary jig. The ore used for the work contained 6 per cent. of mineral—about half sphalerite and the balance galena, with a quartzose gangue. The jig was bedded with material sized between 5.2 and 6.6 mm. The first compartment was bedded with a clean galena, the

second with sphalerite, and the third, fourth, and fifth with mixtures of sphalerite and quartz. The thickness of the bedding averaged from 20 to 30 mm. at the beginning of the run. All beds naturally tended to increase in thickness, since no products were skimmed off during the run.

The jig differed in no respect from the common type of Harz jig. Each sieve-compartment was 16 by 20 in. (406 by 512 mm.) in section, with pistons of equal area. The lengths of strokes could be adjusted between limits of 0 to 50 mm., and within a considerable range in the number per min.—in the experiments, from 175 to 180. The actual piston-speeds used ranged about as follows: first compartment, 75 mm.; second, 66 to 70 mm.; third, 57 to 67 mm.; fourth, 45 to 58 mm.; and fifth, 45 to 50 mm. per sec. Only the hutch-products and tailings were examined.

The ore, sized between 0 and 4.8 mm., round hole, was delivered to the jig through a centrifugal pump. All products traveled in closed circuits, and were finally returned to the centrifugal elevator or pump to be passed again over the jig. The spigots constantly discharged their products, and from these discharges time-samples were cut out. The run occupied exactly an hour, so that after weighing each of the products—in this case six—with the tailings, data were at hand for calculating the capacities; and after screening, weighing, and analyzing, a complete record of the run was made. The results of these tests showed that the differences in length of stroke, or number of strokes per min., were not sufficient to produce a marked difference in the character of the concentrate; that most of the galena was saved in the first hutch and most of the sphalerite in the second; that the third, fourth, and fifth hutches carried very little galena, but more sphalerite. It was found that the first hutch-product contained 57 per cent. of galena, and of this nearly 70 per cent. was larger than 1 mm. in diameter; and that sizes finer than this contained more quartz and less galena. The results seemed to indicate the necessity of first removing stuff less than 0.4 mm. in diameter in order to increase the richness of the product. The first hutch-product contained no coarse sphalerite, and only when the material was as small as 0.2 mm. was any considerable amount present. This seems to indicate that an almost perfect

separation of these two minerals (galena and sphalerite) from each other and quartz, under the conditions with which the jig was operated, was possible if the feed had been sized between the limits of 0.4 and 4.8 mm. The second hutch, which carried most of the sphalerite, shows that the coarse sizes pass through the sieve of the jig less readily than galena. Not until the material was reduced to 1.5 mm. was any marked percentage noticeable in the product. From 0.4 to 1.5 mm. most of the saving was made. Evidently, the cause for so little very fine stuff in the second hutch-product was owing to the fact that most of it was caught in the first. Under the conditions obtaining in the second compartment, a very satisfactory separation could be made on all sizes below 1.5 mm. The results from the third compartment were like those of the second. The fourth and fifth hutches indicated a further saving of sphalerite, but between somewhat different size-limits than in the second and third; the limits in the last two compartments varied between 0.7 and 2.5 mm., with very little fine stuff. This result indicates that in the first compartments more fine material is present, making a denser and more impervious bed, and that the large grains cannot so easily pass through it; and that in the last compartment the bed is more open and porous, and hence larger grains can more readily pass into the hutch. An examination of the tailings indicated that the loss in the fine material was very small, but by far the largest loss was in the four coarsest sizes, which were mixed grains or middlings, and to reduce this loss further crushing must be done. The results indicate that in order to separate sphalerite and quartz, a jig of at least three compartments should be used; since smaller differences in the specific gravity of these minerals require a longer time to effect the separation. In the case of a heavy mineral, such as galena, one or two compartments will effect a perfect separation.

IV. Experiments with the Jarvis Laboratory-Jig.

In order to investigate particularly the effect of pulsion and suction upon jigging, and upon accelerated and retarded strokes, I designed a special jig, with which I conducted a series of experiments and obtained the following results:

1. *Construction.*

Figs. 1, 2, and 3 are detailed drawings of the Jarvis laboratory-jig, with the exception of the variable-speed shaft, which is of the ordinary disk-and-friction-wheel pattern. Figs. 4 and 5 show the designs of the cams used. The screen-area in this jig is 8 by 12 in. (203.2 by 304.8 mm.), with a piston of equal area. With an adjustable dam, the height of discharge may be varied from 3 to 4.5 in. (76.2 to 114.3 mm.). In order to study the behavior of the ore-column and bedding during the process of jigging, one side of the jig-box was made of plate glass. Three types of strokes were employed: (1) The eccentric, adjustable within the limits of 0 and 2 in. (0 and 50.8 mm.). (2) Circular-arc cams, where the period of pulsion occupies three-fourths of the revolution of the cam, or eccentric shaft, and suction one-fourth; or by reversing the direction of rotation of the cam-shaft, or slipping the hub and cam off the shaft and turning it end for end, the times or periods are reversed respectively for pulsion and suction. Cams were made having throws up to 2 in. (50.8 mm.), but only the three shortest throws were used—namely, 1 in. (25.4 mm.), 0.5 in. (12.7 mm.), and 0.25 in. (6.35 mm.). (3) Involute cams, in which the periods were divided into thirds, *i.e.*, one-third of the revolution of the cam-shaft devoted to pulsion, and two-thirds to suction; or as noted above, by reversing the direction of rotation of the cam these periods were reversed. All cams were made of wood, and quickly and easily attached to a cast-iron hub, and by means of a set-screw fastened to the shaft, as shown in full in Fig. 4. Circular-arc and involute cams indicate the character of the curves. The circular-arc cams do not give a uniform motion; or in other words, the cam in describing equal arcs in either the pulsion- or suction-period does not cause the piston to travel equal distances. In the involute cams, however, in either pulsion- or suction-periods, equal arcs give equal distances for piston-travel. The manner of communicating motion from the cams or eccentric is clearly indicated in Figs. 1 and 2. These engage with a brass roller attached to a wrought-iron yoke moving between vertical guides. In order to steady and support the yoke still more, a steel rod is attached to the upper end, passing through a hole in a cross-beam, and is attached to the lower end of the yoke of the piston-rod. The roller, yoke, and piston are actuated

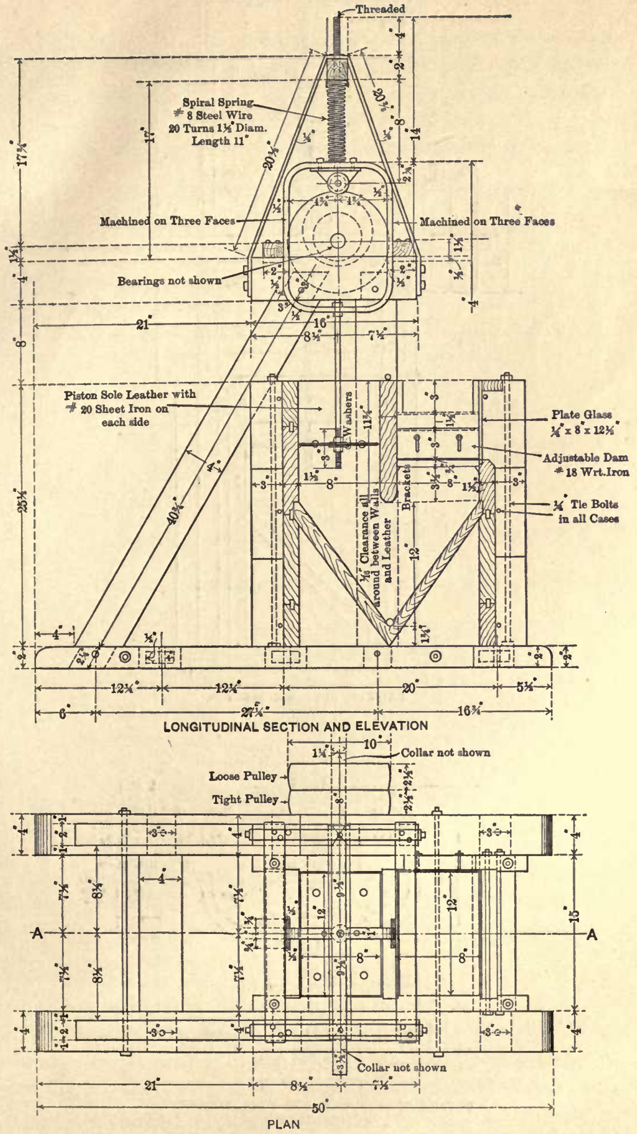
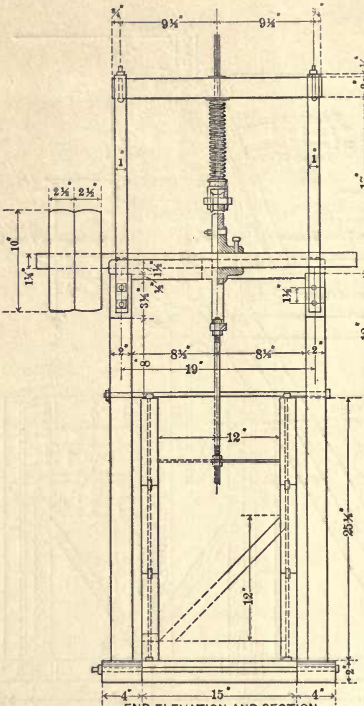
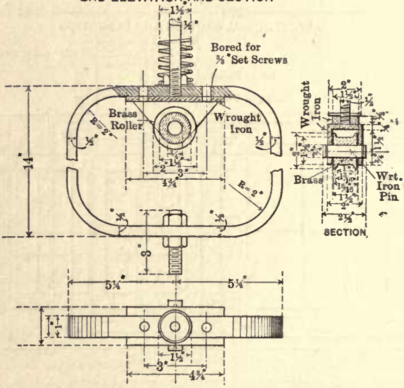


FIG. 1.—THE JARVIS LABORATORY-JIG, LONGITUDINAL SECTION AND ELEVATION, AND PLAN.



END ELEVATION AND SECTION



DETAILS OF WROUGHT IRON YOKE, ROLLER
AND BRACKET

FIG. 2.—THE JARVIS LABORATORY-JIG, END ELEVATION AND SECTION, AND DETAILS OF YOKE, ETC.

positively by the cam on the up-stroke, and to secure a strong and quick down-stroke, a spring of 60 lb. pressure per linear inch of compression was employed. This elastic pressure insured a uniform contact of the roller and cam. It is evident that a large number of styles of cam-curves may be used

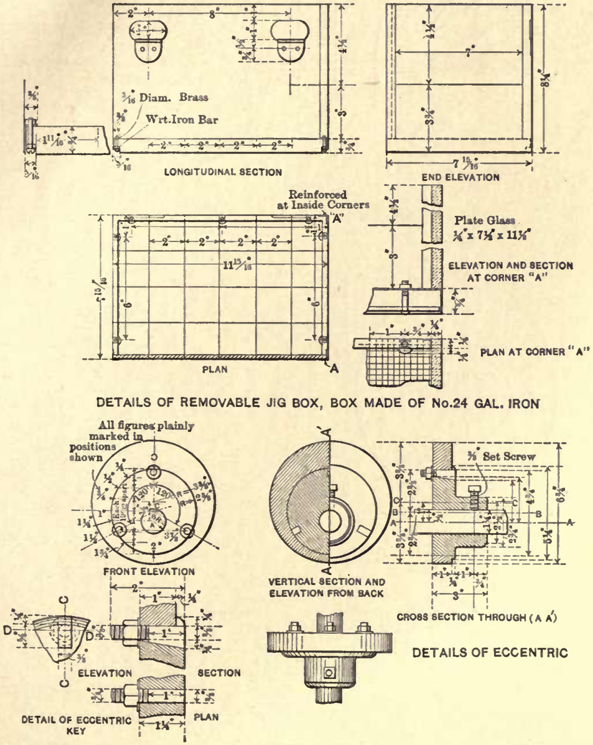


FIG. 3.—THE JARVIS LABORATORY-JIG, DETAILS OF JIG-BOX AND ECCENTRIC.

with this device, and the period of movement of the piston may be varied almost infinitely. It is to be observed, also, that in this system the piston, in all positions, is perfectly horizontal. The piston is made of a single piece of sole-leather, securely riveted between two heavy plates of galvanized iron. With these materials the piston can be run with very little

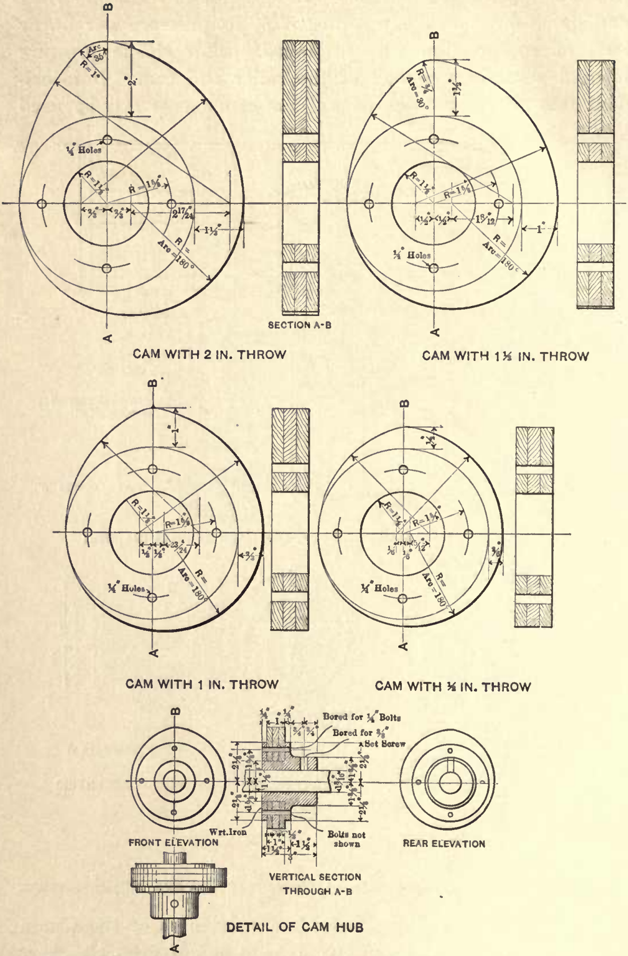


FIG. 4.—THE JARVIS LABORATORY-JIG, ELEVATIONS AND SECTIONS OF CIRCULAR-ARC WOODEN CAMS.

clearance, and there is no danger of warping, swelling, or getting out of repair very easily. The hutch-box sloped from three

sides, at an angle exceeding 50°, to a single spigot in one side of the jig. It was found that at this angle little or no hutch-work collected on the sides, and its entire removal was easily effected. The jig was driven by a 1-h.p. electric motor through the variable-speed counter-shaft. The sieve was supported in a galvanized-iron skeleton, which was removable from the jig-box itself, and different sized screens could readily be inter-

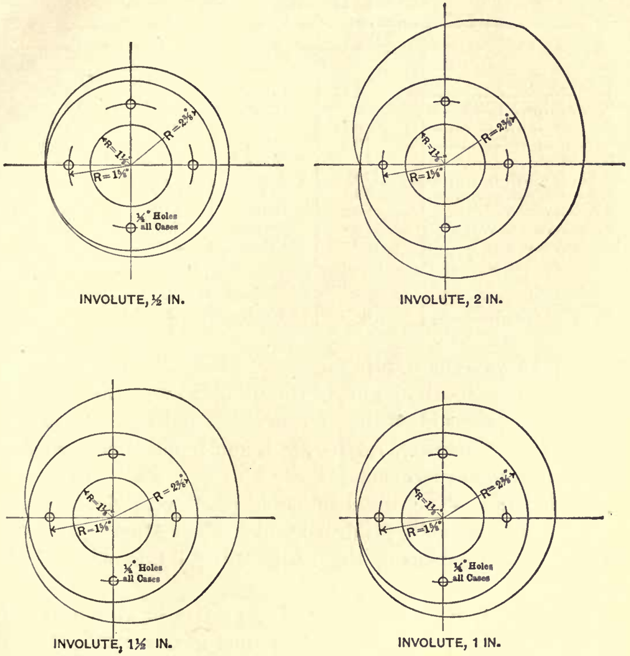


FIG. 5.—THE JARVIS LABORATORY-JIG, CURVES OF INVOLUTE CAMS.

changed. In the tests hereinafter described, only one size sieve—an 8-mesh one—was used.

2. *Materials and Other Accessories.*

A. *Screens.*—Table II. gives the number and mesh of the screen, and the size of the aperture in inches and millimeters. In all cases the holes were square. The size of the hole in the first five sizes was determined by measuring the wire with a wire-

gauge, and counting the number of meshes in a given length. For the remaining screens the diameter of hole was determined by measuring the diameter of the wire and the aperture with a microscopic micrometer, each value given being the mean of several determinations.

B. *Sieve-Sizes.*—The data pertaining to the sieve-sizes are given in Table II.

TABLE II.—*Sieve-Sizes.*

No.	Mesh.	Kind.	Size of Aperture.	
			Inch.	Mm.
1	4	Brass.	0.2097	5.326
2	6	Brass.	0.1382	3.510
3	8	Brass.	0.0966	2.453
4	10	Steel.	0.0841	2.136
5	12	Brass.	0.0654	1.661
6	20	Brass.	0.0381	0.970
7	40	Brass.	0.0165	0.420
8	60	Brass.	0.0102	0.260
9	80	Brass.	0.0082	0.210
10	100	Brass.	0.0063	0.160
Jig-Sieve.				
1	8	Steel.	0.097	2.464

C. *Bedding.*—The bedding used in all the following tests was sized between the limits of 3.510 and 5.326 mm., or through the 4-mesh sieve and on the 6-mesh sieve, and was maintained at the same thickness, 1.5 in. (38.1 mm.), upon the jig-sieve throughout the experiments.

D. *Minerals.*—The three minerals used were fairly pure. The quartz was kindly furnished by Professor Munroe, and the sphalerite and galena by the Foote Mineral Co., of Philadelphia, Pa.

E. *Specific Gravities.*—The specific gravity of each mineral was: galena, 6.66; sphalerite, 3.74; and quartz, 2.62.

The low specific gravity of the two metallic minerals indicates that they are not pure, and an examination revealed the presence of included quartz and minute quantities of other minerals. In crushing these minerals, all the quartz particles that could be picked out by hand were removed. The values given, however, are those obtained for the crushed minerals, ready to be added to the feed.

These three minerals were selected since zinc-blende and galena represent about the minimum and maximum limits

respectively of the ores usually treated on jigs. In thus examining the two limits, the behavior of intermediate minerals could be closely predicted.

F. *Feed.*—The feed in all the tests was crushed by stages until small enough to pass the 10-mesh (2.136 mm.) screen. This size represented the maximum, from which it varied to that of the finest dust. Two classes of feed were employed. The first contained 10 per cent., by weight, of heavy mineral (galena or blende), and the second 20 per cent. of heavy mineral. The balance was, respectively, 90 or 80 per cent. of quartz. Table III. shows the screen-analysis of the three minerals constituting the feed.

TABLE III.—*Screen-Analysis of Minerals in Feed.*

All through 10-mesh (2.136 mm.), and on, mesh,	12.	20.	40.	60.	80.	100.	Through. 100.	
On, mm.,	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
Mineral.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Total.
Galena,	9.6	23.1	26.3	10.8	5.4	2.8	21.2	99.2
Sphalerite,	10.5	24.5	26.8	10.5	5.4	2.9	18.6	99.4
Quartz,	17.1	29.1	26.4	7.5	4.5	2.3	11.0	99.0

The values in Table III. represent the mean of three or four different determinations, made after crushing a large lot and thoroughly sampling it down.

Table IV. shows the calculated percentages of galena and quartz in the two classes of feed, based upon the screen-analysis of the pure minerals given in Table III.

TABLE IV.—*Analyses of Ten- and Twenty-Per Cent. Galena Feed.*

	Ten-Per Cent. Galena Feed.							
Mesh. inch / mm.	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	Thro' 100. 0.16	Average. ....
	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.
Quartz.........	94.1	92.0	90.0	88.8	88.2	88.1	82.3	89.1
Galena.........	5.9	8.0	10.0	11.2	11.8	11.9	17.7	10.9
	Twenty-Per Cent. Galena Feed.							
	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.
Quartz.........	87.7	83.4	80.0	77.7	77.3	76.8	67.7	78.7
Galena.........	12.3	16.6	20.0	22.7	22.3	23.2	32.3	21.3

The results obtained for sphalerite and quartz are given in Table V.

TABLE V.—*Analyses of Ten- and Twenty-Per Cent. Sphalerite Feed.*

	Ten-Per Cent. Sphalerite Feed.							
Mesh. {inch / mm.	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	Thro' 100. 0.16	Average. ....
	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.
Quartz.........	93.6	91.5	90.0	89.2	88.3	87.7	84.6	89.3
Sphalerite.....	6.4	8.5	10.0	10.8	11.7	12.3	15.4	10.7
	Twenty-Per Cent. Sphalerite Feed.							
	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.
Quartz.........	86.7	82.7	80.0	78.3	77.0	75.9	70.4	78.7
Sphalerite.....	13.3	17.3	20.0	21.7	23.0	24.1	29.6	21.3

In Tables IV. and V. the columns for each of the respective feeds show the percentages of each of the two minerals on the different screen-sizes. Thus, in Table IV., with 10 per cent. of galena, the stuff resting on the 12-mesh (1.66 mm.) sieve contained 94.1 per cent. of quartz and 5.9 per cent. of galena, etc.

With both sphalerite and galena, the screen-analyses, and from these the calculated percentages of the mineral-content of each screen-size, show that more fine material is produced in crushing these softer minerals than in crushing quartz. The finest size of the 10 and the 20 per cent. galena or sphalerite shows a much higher percentage of these minerals than the average of the feed, as shown in Tables IV. and V.

3. *Method of Conducting the Tests.*

In beginning a series of tests on a given feed, the exact proportion of each mineral was weighed out, so that the total quantity was 35 lb. (15.87 kg.). Meanwhile, the sieve had received its bedding, 1.5 in. (38.1 mm.), and the hutch-box and jig were filled with water; the tailings-trough placed in position, connecting with a large tub in which all the overflow and tailings were caught; the feed thoroughly wetted down (if fresh material); power was turned on and the jig started. In case it was the first run of a series, the jig-box containing bedding only, the feed was rapid until this was filled with the mixture, after which the feeding proceeded at the regular rate.

The feeding was accomplished by filling with the ore-mixture a large flat-bottomed scoop, of a width slightly less than that of the jig-compartment, 8 in. (203.2 mm.), and with a small and constant stream of water washing the material from the scoop on to the jig. While the speed of jigging and the rate of feeding varied, the object always aimed at was to feed the jig just as fast as it appeared able to treat the material. The discharge was watched constantly to see if any particles of heavy mineral were being carried into the tailings. If so, the rate of feeding was reduced. Close watch was also kept on the jig-bed, and if the jig showed symptoms of clogging up, due to rapid feeding, the rate of feed was immediately decreased.

At the end of the run, usually from 8 to 15 min., the jig was stopped, the water-supply cut off, and the hutch-products drawn off into suitable vessels. After allowing the material to settle, the water was carefully decanted and the products thoroughly mixed, and a sample of about 125 g. cut out, which was dried, and later exactly 100 g. of this sample was weighed out on a pulp-balance and sized on a nest of sieves, ranging from 12-mesh (1.66 mm.) through 100-mesh (0.16 mm.), and each size carefully weighed; finally, the percentage of galena or sphalerite in each sieve-size was determined. The analyses of the products were made in several ways. In the first two or three coarse sizes good results were obtained by weighing out 1 or 2 g. and picking out the quartz or other mineral by hand and then weighing again; also, by comparing with standard mixtures of quartz and galena or sphalerite. In the small sizes vanning-tests were made.

After the completion of a run, the tailings, which were given ample time in which to allow the fine material to settle and the water to be decanted off, were again mixed with the product from the hutch and formed the feed for another test. The material was thus used repeatedly until all the tests had been completed for a particular series or class. The material remaining in the jig-box was not cleaned out from test to test, unless another feed was to be employed. The investigations had to do only with what passed into the hutch, and determinations upon the character and nature of what remained on the sieve, except as it could be examined through the glass side of the jig, were not made.

4. *Record of Results.*

In the following records are five horizontal rows of figures: in the topmost row, the sieve-mesh; in the next lower row, the corresponding size in millimeters of the aperture upon which the material was caught; and three lower rows marked "*A*," "*B*," and "*C*" respectively. The first of these, *A*, gives the weights in grams of the different sieve-sizes; and since these are all on a basis of 100 g. the weights, therefore, represent percentages as well. Row *B* gives the percentage of heavy mineral, galena or sphalerite, in each of the sieve-products, and the balance in every case is quartz. Row *C* gives the weight of heavy mineral contained in each of the sieve-sizes, and is obtained by multiplying the weights in row *A* by the respective percentages in the *B* row. The sum of the products in the *C* row gives the number of grams of mineral in 100 g. of the concentrate, or in other words, the percentage.

Under the stroke of each experiment are given: (1), the number of revolutions of the cam or eccentric shaft per minute; (2) the length in inches and millimeters; (3) the kind of stroke; (4) pulsion, in which the fractions $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{2}{3}$, and $\frac{3}{4}$ refer to the fractional part of the entire revolution of the cam or shaft in which this movement took place. The smaller this fraction the quicker the movement. The rates or velocities are set opposite. The same is true for the period of suction.

The observed pulsion- and suction-velocities noted in the following tests and elsewhere in this paper are to be understood as the mean piston-velocities, or the velocities of the water-column in the free part of the jig-column, and not the actual current-velocities acting upon a mass of grains constituting the jig-bed.

In studying these experiments, reference should be made to Figs. 6 to 13, inclusive, in which row *C* is shown graphically, representing the mean diameter of grains.

TEST 1.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind: Circular-arc cam.
Pulsion: $\frac{1}{4}$ (270.7 mm.) = 10.66 in. per sec.
Suction: $\frac{3}{4}$ (90.2 mm.) = 3.55 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	3.3	11.6	36.0	18.4	9.5	4.7	16.0	99.5
B.	100.0	80.0	35.0	20.0	15.0	20.0	28.0	
C.	3.3	9.3	12.6	3.7	1.4	0.9	4.5	35.7

Percentage of galena in concentrates: 35.7.

Ratio of concentration based on original feed: 3.57.

Remarks.—All the material on the jig-bed pulsated—the material above having a longer amplitude than the grains deeper down. It was observed that the bedding-grains at the top moved nearly 0.75 in. vertically, while those at the bottom of the bed next to the screen moved about 0.25 in.

Test 2.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind: Circular-arc cam.
Pulsion: $\frac{3}{4}$ (90.2 mm.) = 3.55 in. per sec.
Suction: $\frac{1}{4}$ (270.7 mm.) = 10.66 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	0.7	7.0	26.5	22.2	14.0	6.6	22.3	99.3
B.	100.0	95.0	60.0	35.0	25.0	20.0	30.0	
C.	0.7	6.6	15.9	7.7	3.5	1.3	6.7	42.4

Percentage of galena in concentrates: 42.2.

Ratio of concentration based on original feed: 4.24.

Remarks.—Some movement of the bedding-grains, especially near the top, but only a few grains of galena were visible in the interstitial spaces of the bedding. The ore-column pulsated violently, and between the bedding and the ore was a zone in very active motion, while above the column of ore was quite compact.

Test 3.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind: Involute cam.
Pulsion: $\frac{1}{3}$ (203.2 mm.) = 8 in. per sec.
Suction: $\frac{2}{3}$ (101.6 mm.) = 4 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	2.4	12.7	35.6	18.0	10.3	5.6	14.7	99.3
B.	95.0	75.0	25.0	16.0	15.0	15.0	20.0	
C.	2.3	10.5	8.0	3.0	1.5	0.8	2.0	29.9

Percentage of galena in concentrates: 29.9.

Ratio of concentration based on original feed: 2.99.

Remarks.—The bedding and with it the ore-column pulsated. The grains of bedding were kept in constant circulation. Very few grains of galena could be seen in the interstitial spaces of the bedding, but were free. It was evident, therefore, that if a galena- or quartz-grain got as far as the bedding it had little opportunity of remaining there.

Test 4.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind: Involute cam.
Pulsion: $\frac{2}{3}$ (101.6 mm.) = 4 in. per sec.
Suction: $\frac{1}{3}$ (203.2 mm.) = 8 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	0.4	7.8	39.7	21.4	10.7	4.7	14.8	99.5
B.	60.0	50.0	25.0	22.0	18.0	18.0	22.0	
C.	0.2	3.9	9.9	4.7	1.9	0.8	3.2	24.6

Percentage of galena in concentrates: 24.6.

Ratio of concentration based on original feed: 2.46.

Remarks.—The ore-bed pulsated violently, but not so much so as with the strong suction of the circular-arc cam in Test 3. The grains of the bed did not behave exactly alike, and the middle of the bed contained some grains of galena.

Test 5.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind: Eccentric.
Pulsion and Suction: $\frac{1}{2}$ (135.5 mm.) = 5.33 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	1.4	9.0	34.0	20.5	11.7	6.0	17.2	99.8
B.	95.0	95.0	35.0	20.0	20.0	20.0	28.0	
C.	1.3	8.5	11.9	4.1	2.3	1.2	4.8	34.1

Percentage of galena in concentrates: 34.1.

Ratio of concentration based on original feed: 3.41.

Remarks.—The entire bed pulsated much more uniformly than in Tests 3 and 4. The bedding-grains were free to move, and tended to move in convection-currents. No particles of galena collected on top of the bedding, and few could be seen in the interstitial spaces.

Test 6.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, $\frac{1}{2}$ in. (12.7 mm.).
Kind: Eccentric.
Pulsion and Suction: $\frac{1}{2}$ (67.7 mm.) = 2.66 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	......	2.7	26.8	20.7	13.2	10.0	26.2	99.6
B.	......	95.0	78.0	48.0	33.0	27.0	38.0	
C.	......	2.5	20.9	9.9	4.3	2.7	9.9	50.2

Percentage of galena in concentrates: 5.02.

Ratio of concentration based on original feed: 50.2.

Remarks.—The lower third of bedding quite fixed, while the upper two-thirds pulsated, but the grains did not change positions—moving *en masse*. The ore-column pulsated regularly, and between the bedding and the ore was a zone of great mobility. The action and movement going on in the ore-column resembled very much that taking place in a hydraulic classifier.

Test 7.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, $\frac{1}{2}$ in. (12.7 mm.).
Kind: Circular-arc cam.
Pulsion: $\frac{1}{4}$ (135.5 mm.) = 5.33 in. per sec.
Suction: $\frac{3}{4}$ (45.2 mm.) = 1.77 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	0.8	6.4	24.7	21.4	13.2	7.5	26.0	100.0
B.	100.0	97.0	60.0	35.0	18.0	20.0	27.0	
C.	0.8	6.2	14.8	7.5	2.3	1.5	7.0	40.1

Percentage of galena in concentrates : 40.1.

Ratio of concentration based on original feed : 4.01.

Remarks.—The bedding and the ore-column pulsated uniformly—the top having a longer amplitude and extending over a longer time than the grains nearer the bottom. Ore-column very mobile and in active circulation. The upper third of bedding contained many particles of galena.

TEST 8.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, ½ in. (12.7 mm.).
Kind : Circular-arc cam.
Pulsion : ¾ (45.2 mm.) = 1.77 in. per sec.
Suction : ¼ (135.5 mm.) = 5.33 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	......	2.1	26.0	24.4	14.7	7.1	25.3	99.6
B.	......	90.0	53.0	31.0	20.0	20.0	27.0	
C.	......	1.9	13.8	7.5	2.9	1.4	6.8	34.3

Percentage of galena in concentrates : 34.3.

Ratio of concentration based on original feed : 3.43.

Remarks.—Only the top third of bedding showed any signs of movement, but the interstitial spaces were filled with particles of galena. The particles in the ore-column tended to circulate in two opposite and distinct paths.

TEST 9.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, ½ in. (12.7 mm.).
Kind : Involute cam.
Pulsion : ⅓ (101.6 mm.) = 4 in. per sec.
Suction : ⅔ (50.8 mm.) = 2 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	1.3	10.3	27.9	20.5	11.9	6.4	21.2	99.5
B.	100.0	100.0	72.0	31.0	22.0	20.0	31.0	
C.	1.3	10.3	20.0	6.3	2.6	1.3	6.5	48.3

Percentage of galena in concentrates : 48.3.

Ratio of concentration based on original feed : 4.83.

Remarks—Both the bedding and the ore-column pulsated—the top having a longer amplitude of vibration and requiring a longer time than the grains nearer the bottom. Many grains of galena in the upper third of bedding and decreasing below. The ore-column very mobile, and line between bedding and ore horizontal and uniformly even.

TEST 10.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, ½ in. (12.7 mm.).
Kind : Involute cam.
Pulsion : ⅔ (50.8 mm.) = 2 in. per sec.
Suction : ⅓ (101.6 mm.) = 4 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	......	1.0	26.4	25.1	13.7	7.2	26.5	99.9
B.	......	90.0	70.0	30.0	28.0	26.0	32.0	
C.	......	0.9	20.5	7.5	3.8	1.8	8.5	43.0

Percentage of galena in concentrates : 43.0.

Ratio of concentration based on original feed : 4.30.

Remarks.—The bedding-grains were practically stationary—neither pulsation nor movement among themselves, and were filled with particles of galena. The ore-column pulsated, but was not mobile except for a zone 0.5 in. teick on top of the bedding. Evidently too much suction.

Test 11.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, $\frac{1}{4}$ in. (6.35 mm.).
Kind : Involute cam.
Pulsion : $\frac{1}{3}$ (50.8 mm.) = 2 in. per sec.
Suction : $\frac{2}{3}$ (25.4 mm.) = 1 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	......	2.4	24.1	20.0	16.3	9.4	27.8	100.0
B.	......	95.0	92.0	56.0	35.0	22.0	25.0	
C.	......	2.3	22.1	11.2	5.7	2.0	5.7	49.0

Percentage of galena in concentrates : 49.0.

Ratio of concentration based on original feed : 4.90.

Remarks.—The bedding, as a whole, did not pulsate, but the grains in the upper part of the bedding showed some movement, and this portion was filled with particles of galena. The ore-column was very mobile and pulsated regularly and uniformly. The large grains of quartz rested directly upon the bedding, with the finer quartz-particles above.

Test 12.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, $\frac{1}{4}$ in. (6.35 mm.).
Kind : Involute cam.
Pulsion : $\frac{2}{3}$ (25.4 mm.) = 1 in. per sec.
Suction : $\frac{1}{3}$ (50.8 mm.) = 2 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	......	1.4	20.4	24.5	18.8	9.1	25.5	99.7
B.	.....	80.0	62.0	40.0	27.0	24.0	25.0	
C.	......	1.1	12.6	9.8	5.0	2.2	6.3	37.0

Percentage of galena in concentrates : 37.0.

Ratio of concentration based on original feed : 3.7.

Remarks.—The bedding did not move at all. The ore-bed seemed to be quite mobile immediately above the bedding, but compact close to the top.

Test 13.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, $\frac{1}{4}$ in. (6.35 mm.).
Kind : Circular-arc cam.
Pulsion : $\frac{1}{4}$ (67.7 mm.) = 2.66 in. per sec.
Suction : $\frac{3}{4}$ (22.5 mm.) = 0.88 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	......	4.2	24.8	25.5	15.1	7.3	23.1	100.0
B.	......	95.0	62.0	26.0	20.0	18.0	27.0	
C.	......	4.0	15.3	6.6	3.0	1.3	6.3	36.5

Percentage of galena in concentrates: 36.5.

Ratio of concentration based on original feed: 3.65.

Remarks.—The bedding and the ore-column pulsated, but the grains of bedding were not sufficiently mobile to rearrange themselves, although the upper third was much more mobile and pulsated much more than the bottom, and many particles of galena were contained in the interstitial spaces of the upper third of bedding. The entire ore-column was very free and mobile and pulsated uniformly.

Test 14.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, $\frac{1}{4}$ in. (6.35 mm.).
Kind: Circular-arc cam.
Pulsion: $\frac{3}{4}$ (22.5 mm.) = 0.88 in. per sec.
Suction: $\frac{1}{4}$ (67.7 mm.) = 2.66 in per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	......	2.0	24.6	22.6	14.4	7.0	29.4	100.0
B.	......	94.0	62.0	25.0	20.0	22.0	33.0	
C.	......	2.0	15.2	4.6	2.9	1.5	9.7	35.9

Percentage of galena in concentrates: 35.9.

Ratio of concentration based on original feed: 3.59.

Remarks.—No movement in the bedding, although the top bedding-grains showed some tendency to move, and many particles of galena could be seen in the upper third of the bedding. The ore-column pulsated regularly, and was quite compact.

Test 15.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, $\frac{1}{4}$ in. (6.35 mm.).
Kind: Eccentric.
Pulsion and Suction: $\frac{1}{2}$ (33.9 mm.) = 1.33 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	......	0.4	17.8	23.9	17.2	9.3	31.0	99.6
B.	......	85.0	63.0	31.0	20.0	20.0	30.0	
C.	......	0.3	11.2	7.4	3.4	1.8	9.3	33.4

Percentage of galena in concentrates: 33.4.

Ratio of concentration based on original feed: 3.34.

Remarks.—The bedding was quite fixed in position, and the upper part well filled with grains of galena. It was noticed that when the feed was too fast, an inclined line, beginning at the top of the bedding at the back of the jig-box, and sloping up nearly to the top of the ore-column at the front or discharge was formed. Otherwise the ore-column was mobile, with the coarse particles of quartz resting above the bedding, and the finer particles arranged above.

Test 16.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 320. Length, $\frac{1}{4}$ in. (6.35 mm.).
Kind: Eccentric.
Pulsion and Suction: $\frac{1}{2}$ (67.7 mm.) = 2.66 in. per sec.

On mesh.....	12.	20.	40.	60.	80	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	0.8	6.4	31.5	26.9	11.9	5.8	16.4	99.7
B.	100.0	98.0	60.0	25.0	15.0	20.0	30.0	
C.	0.8	6.4	18.9	6.7	1.8	1.1	4.9	40.6

Percentage of galena in concentrates : 40.6.

Ratio of concentration based on original feed : 4.06.

Remarks.—Both the bedding and the ore-column pulsated regularly—the grains near the top of the bedding having a longer amplitude of vibration than those near the bottom, and the same being true of the grains in the ore-column. The ore-column was very mobile. The jig worked fast.

Test 17.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 320. Length, $\frac{1}{8}$ in. (3.17 mm.).
Kind : Eccentric.
Pulsion and Suction : $\frac{1}{2}$ (33.9 mm.) = 1.33 in. per sec.

On mesh..... Size in mm..	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	thro' 100. 0.16	Total.
A.	......	4.2	31.3	27.2	13.5	6.4	17.4	100.0
B.	......	95.0	35.0	21.0	18.0	18.0	28.0	
C.	......	4.0	10.9	5.7	2.4	1.1	4.9	29.0

Percentage of galena in concentrates : 29.0

Ratio of concentration based on original feed : 2.90.

Remarks.—The entire bed pulsated, and the bedding contained many particles of galena and some quartz. As noted before, the top had a longer amplitude of vibration than the bottom, and required a longer time. The ore-column pulsated regularly, and the fine material (quartz) was carried down to the bedding so that it was distributed quite regularly throughout the ore. The ore-column was compact.

Test 18.—*Galena* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 400. Length, $\frac{1}{16}$ in. (1.59 mm.).
Kind : Eccentric.
Pulsion and Suction : $\frac{1}{2}$ (21.2 mm.) = 0.83 in. per sec.

On mesh..... Size in mm..	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	thro' 100. 0.16	Total.
A.	......	2.6	37.3	26.0	12.1	5.8	16.1	99.9
B.	......	100.0	25.0	23.0	16.0	15.0	26.0	
C.	......	2.6	9.3	6.0	1.9	0.8	4.2	24.8

Percentage of galena in concentrates : 24.8.

Ratio of concentration based on original feed : 2.48.

Remarks.—The grains of the bedding were not very mobile, and only the top layer of grains showed any indication of pulsating. The base of the ore-column was distinguished by a zone of active agitation. Above this zone, which was only 0.5 in. thick, the ore-column was compact and not mobile. The bedding-grains contained only a few galena-grains in the upper third portion, but the interstitial spaces were filled with quartz. In the middle and lower third portions of the bedding, many more grains of galena were visible, being more abundant in the middle third.

Test 21.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind: Circular-arc cam.
Pulsion: $\frac{1}{4}$ (270.7 mm.) = 10.66 in. per sec.
Suction: $\frac{3}{4}$ (90.2 mm.) = 3.55 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	4.3	18.1	33.2	16.7	8.5	4.0	14.8	99.6
B.	100.0	90.0	55.0	50.0	40.0	40.0	50.0	
C.	4.3	16.2	18.1	8.5	3.4	1.6	7.5	59.6

Percentage of galena in concentrates: 59.6.
Ratio of concentration based on original feed: 2.98.
Remarks.—Movement of jig-bed same as Test 1.

Test 22.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind: Circular-arc cam.
Pulsion: $\frac{3}{4}$ (90.2 mm) = 3.55 in. per sec.
Suction: $\frac{1}{4}$ (270.7 mm.) = 10.66 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	0.5	6.6	30.4	19.6	11.5	5.6	25.7	99.9
B.	100.0	90.0	65.0	55.0	45.0	45.0	50.0	
C.	0.5	5.9	19.5	11.0	5.1	2.5	12.8	57.3

Percentage of galena in concentrates: 57.3.
Ratio of concentration based on original feed: 2.86.
Remarks.—Movement of jig-bed similar to Test 2.

Test 23.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind: Involute cam.
Pulsion: $\frac{1}{3}$ (203.2 mm.) = 8 in. per sec.
Suction: $\frac{2}{3}$ (101.6 mm.) = 4 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	3.4	16.5	32.4	18.0	9.2	4.3	15.6	99.4
B.	100.0	95.0	55.0	40.0	40.0	40.0	45.0	
C.	3.4	15.6	17.6	7.2	3.6	1.6	7.0	56.0

Percentage of galena in concentrates: 56.0.
Ratio of concentration based on original feed: 2.80.
Remarks.—Movement of bed similar to Test 3.

Test 24.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind: Involute cam.
Pulsion: $\frac{2}{3}$ (101.6 mm.) = 4 in. per sec.
Suction: $\frac{1}{3}$ (203.2 mm.) = 8 in. per sec.

On mesh.... / Size in mm..	12. / 1.66	20. / 0.97	40. / 0.42	60. / 0.26	80. / 0.21	100. / 0.16	thro' 100. / 0.16	Total.
A.	1.5	12.2	34.0	20.0	10.2	4.8	17.5	100.2
B.	95.0	80.0	56.0	45.0	40.0	45.0	45.0	
C.	1.4	9.6	18.7	9.0	4.0	2.1	7.7	52.5

Percentage of galena in concentrates: 52.5.

Ratio of concentration based on original feed: 2.62.

Remarks.—The entire bed pulsated, but not so violently as No. 23. The ore-column pulsated much more than the bedding, and the top of the bedding than the bottom. Between the bedding and the ore-column was a zone 0.5 in. thick of great activity. Few grains in the interstitial spaces of the bedding. Jigged rapidly.

Test 25.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind: Eccentric.
Pulsion and Suction: $\frac{1}{2}$ (135.5 mm.) = 5.33 in. per sec.

On mesh.... / Size in mm..	12. / 1.66	20. / 0.97	40. / 0.42	60. / 0.26	80. / 0.21	100. / 0.16	thro' 100. / 0.16	Total.
A.	4.6	17.4	28.8	17.1	9.5	5.5	17.2	100.1
B.	100.0	95.0	80.0	50.0	40.0	50.0	45.0	
C.	4.6	17.0	23.7	8.5	3.8	2.2	7.6	67.4

Percentage of galena in concentrates: 67.4.

Ratio of concentration based on original feed: 3.37.

Remarks.—The entire bed pulsated, the upper part having a longer amplitude of vibration and requiring a longer time to complete it than the grains nearer the bottom. Difficult to save the finest grains of galena. The bedding-grains were free to change positions during the pulsion-cycle.

Test 26.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, $\frac{1}{2}$ in. (12.7 mm.).
Kind: Eccentric.
Pulsion and Suction: $\frac{1}{2}$ (67.7 mm.) = 2.66 in. per sec.

On mesh.... / Size in mm..	12. / 1.66	20. / 0.97	40. / 0.42	60. / 0.26	80. / 0.21	100. / 0.16	thro' 100. / 0.16	Total.
A.	0.7	7.3	26.0	16.9	11.7	7.4	29.5	99.5
B.	100.0	100.0	85.0	60.0	45.0	40.0	40.0	
C.	0.7	7.3	22.1	10.2	5.4	2.8	12.0	60.5

Percentage of galena in concentrates: 60.5

Ratio of concentration based on original feed: 3.02.

Remarks.—The entire bed pulsated, and the zone between the bedding and the

ore-column was an active one—the grains in the ore-column were kept in constant circulation. The interstitial spaces in the upper third of the bedding filled with particles of galena.

TEST 27.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, $\frac{1}{2}$ in. (12.7 mm.).
Kind: Circular-arc cam.
Pulsion: $\frac{3}{4}$ (135.5 mm.) = 5.33 in. per sec.
Suction: $\frac{1}{4}$ (45.2 mm.) = 1.77 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro'100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	2.4	15.0	27.9	18.4	11.4	6.0	18.7	99.8
B.	100.0	100.0	85.0	50.0	35.0	35.0	35.0	
C.	2.4	15.0	23.8	9.2	3.8	2.1	6.6	62.9

Percentage of galena in concentrates: 62.9.

Ratio of concentration based on original feed: 3.15.

Remarks.—The entire bed pulsated very uniformly, the top having a longer time to complete it than the grains nearer the bottom. Many grains of galena in the upper part of the bedding, but only a few in the lower half.

TEST 28.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, $\frac{1}{2}$ in. (12.7 mm.).
Kind: Circular-arc cam.
Pulsion: $\frac{1}{4}$ (45.2 mm.) = 1.77 in. per sec.
Suction: $\frac{3}{4}$ (135.5 mm.) = 5.33 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro'100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	0.1	1.7	25.0	22.0	12.7	7.3	31.2	100.0
B.	100.0	95.0	85.0	60.0	45.0	45.0	45.0	
C.	0.1	1.7	21.2	13.2	5.8	3.1	13.9	59.0

Percentage of galena in concentrates: 59.0.

Ratio of concentration based on original feed: 2.95.

Remarks.—The bedding-grains did not pulsate, although those near the top exhibited a slight tendency. The ore-column pulsated, but excepting a zone about 0.5 in. thick immediately above the bedding was otherwise compact. The ore-grains circulated in two distinct and opposite paths.

TEST 29.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, $\frac{1}{2}$ in. (12.7 mm.).
Kind: Involute cam.
Pulsion: $\frac{2}{3}$ (101.6 mm.) = 4 in. per sec.
Suction: $\frac{1}{3}$ (50.8 mm.) = 2 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro'100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	3.4	16.0	25.1	17.2	11.2	6.2	20.7	99.8
B.	100.0	100.0	85.0	60.0	45.0	40.0	45.0	
C.	3.4	16.0	21.2	10.2	4.9	2.4	9.4	67.5

Percentage of galena in concentrates: 67.5.

Ratio of concentration based on original feed: 3.37.

Remarks.—The entire bed pulsated, the upper part, as noted before, having a longer amplitude of vibration and requiring a longer time to complete it than the grains beneath. The upper half of the bedding contained many particles of galena, while only a few were visible in the lower half.

Test 30.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, $\frac{1}{2}$ in. (12.7 mm.).
Kind: Involute cam.
Pulsion: $\frac{2}{3}$ (50.8 mm.) = 2 in. per sec.
Suction: $\frac{1}{3}$ (101.6 mm.) = 4 in. per sec.

On mesh.... / Size in mm..	12. / 1.66	20. / 0.97	40. / 0.42	60. / 0.26	80. / 0.21	100. / 0.16	thro' 100. / 0.16	Total.
A.	0.1	3.0	31.3	21.6	11.5	6.5	25.7	99.7
B.	100.0	95.0	65.0	50.0	40.0	40.0	45.0	
C.	0.1	2.8	20.1	11.0	4.8	2.6	11.7	53.1

Percentage of galena in concentrates: 53.1.

Ratio of concentration based on original feed: 2.65.

Remarks.—The bedding exhibited a slight tendency to pulsate *en masse*. The upper part of the bedding well filled with particles of galena, decreasing rapidly in number below. Immediately above the bedding the ore-column presented a zone of active agitation about 0.5 in. thick, while above the particles seemed quite compact and not very mobile.

Test 31.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, $\frac{1}{4}$ in. (6.35 mm.).
Kind: Involute cam.
Pulsion: $\frac{1}{3}$ (50.8 mm.) = 2 in. per sec.
Suction: $\frac{2}{3}$ (25.4 mm.) = 1 in. per sec.

On mesh.... / Size in mm..	12. / 1.66	20. / 0.97	40. / 0.42	60. / 0.26	80. / 0.21	100. / 0.16	thro' 100. / 0.16	Total.
A.	......	1.4	23.0	17.0	14.6	9.0	35.0	100.0
B.	......	100.0	100.0	85.0	60.0	50.0	45.0	
C.	......	1.4	23.0	14.4	8.7	4.5	15.7	67.7

Percentage of galena in concentrates: 67.7.

Ratio of concentration based on original feed: 3.39.

Remarks.—The upper one-third of the bedding-grains exhibited some tendency to arrange themselves during pulsion, but the lower two-thirds did not move or pulsate. In the upper third were many particles of galena and less below. The ore-column pulsated regularly, the large grains of quartz arranging themselves next to the bedding, the smaller on top. The ore-column was mobile.

TEST 32.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.).
Kind: Involute cam.
Pulsion: ⅔ (25.4 mm.) = 1 in. per sec.
Suction: ⅓ (50.8 mm.) = 2 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro'100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	......	1.2	17.5	26.3	15.4	8.7	30.7	99.8
B.	......	90.0	90.0	55.0	40.0	35.0	40.0	
C.	......	1.1	15.7	14.3	6.0	3.1	12.4	52.6

Percentage of galena in concentrates: 52.6.
Ratio of concentration based on original feed: 2.63.
Remarks.—The bedding did not pulsate. The upper third was filled with particles of galena and decreasing numbers below. The ore-column was somewhat mobile in spots, but pulsated quite regularly, and on top of the bedding was a zone which exhibited considerable activity.

TEST 33.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.).
Kind: Circular-arc cam.
Pulsion: ¼ (67.7 mm.) = 2.66 in. per sec.
Suction: ¾ (22.5 mm.) = 0.88 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro'100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	0.4	5.5	27.0	24.0	13.1	6.5	23.4	99.9
B.	100.0	100.0	60.0	40.0	35.0	35.0	35.0	
C.	0.4	5.5	16.2	9.6	4.5	2.3	8.0	46.5

Percentage of galena in concentrates: 46.5.
Ratio of concentration based on original feed: 2.32.
Remarks.—The upper half and often more of the bedding pulsated. In this part, also, were many particles of galena. The ore-column was mobile, with the large quartz-grains arranged near the top of the bedding and the smaller sizes above.

TEST 34.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.).
Kind: Circular-arc cam.
Pulsion: ¾ (22.5 mm.) = 0.88 in. per sec.
Suction: ¼ (67.7 mm.) = 2.66 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro'100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	......	3.0	27.7	19.2	12.3	7.2	30.5	99.9
B.	......	100.0	85.0	70.0	50.0	50.0	45.0	
C.	......	3.0	23.8	13.3	6.0	3.6	13.5	63.2

Percentage of galena in concentrates: 63.2.
Ratio of concentration based on original feed: 3.16.
Remarks.—The bedding exhibited very little tendency to pulsate, nor was there

any movement among the grains themselves. The upper half of the bedding was well filled with grains of galena. The particles of ore above the bedding circulated in two opposite orbits, passing down at the front and back end of jig and joining in the center.

Test 35.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.).
Kind: Eccentric.
Pulsion and Suction: ½ (33.9 mm.) = 1.33 in. per sec.

On mesh..... Size in mm..	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	thro' 100. 0.16	Total.
A.	......	0.7	17.5	19.2	18.2	8.7	35.2	99.5
B.	......	95.0	95.0	70.0	45.0	45.0	40.0	
C.	......	0.7	16.6	13.3	8.1	3.5	17.5	59.7

Percentage of galena in concentrates: 59.7.

Ratio of concentration based on original feed: 3.

Remarks.—The bedding pulsated slightly, and the upper half was well filled with galena, with decreasing quantities below. The ore-column pulsated regularly, with the largest grains of quartz resting on top of the bedding, decreasing in size above.

Test 36.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 320. Length, ¼ in. (6.35 mm.).
Kind: Eccentric.
Pulsion and Suction: ½ (67. 7 mm.) = 2.66 in. per sec.

On mesh..... Size in mm..	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	thro' 100. 0.16	Total.
A.	0.6	7.2	30.1	22.8	12.3	5.6	21.2	99.8
B.	100.0	100.0	65.0	45.0	40.0	40.0	50.0	
C.	0.6	7.2	19.5	10.2	4.9	2.2	10.6	55.2

Percentage of galena in concentrates: 55.2.

Ratio of concentration based on original feed: 2.76

Remarks.—The entire bed pulsated regularly. The upper part of bedding contained many particles of galena.

Test 37.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 320. Length, ⅛ in. (3.17 mm.).
Kind: Eccentric.
Pulsion and Suction: ½ (33.9 mm.) = 1.33 in. per sec.

On mesh..... Size in mm..	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	thro' 100. 0.16	Total.
A.	......	10.3	27.2	23.1	13.7	7.1	19.0	100.4
B.	......	100.0	85.0	50.0	40.0	40 0	40.0	
C.	......	10.3	23.1	11.5	5.5	2.8	7.6	60.8

Percentage of galena in concentrates: 60.8.

Ratio of concentration based on original feed: 3.04.

Remarks.—The upper third of bedding was quite mobile, and filled with particles of galena, decreasing below. The ore-column seemed quite compact, but pulsated regularly.

TEST 38.—*Galena* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 320. Length, ½ in. (12.7 mm.).
Kind: Eccentric.
Pulsion and Suction: ½ (135.5 mm.) = 5.33 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	4.3	16.4	34.6	18.2	9.0	4.6	13.2	100.3
B.	100.0	95.0	50.0	40.0	35.0	40.0	45.0	
C.	4.3	15.6	17.3	7.3	3.1	1.8	5.9	55.3

Percentage of galena in concentrates: 55.3.

Ratio of concentration: 2.76.

Remarks.—Both ore and bedding pulsated regularly, but violently. Considerable of the finest size of galena could be seen in the tailings. The jig worked very rapidly.

TEST 41.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind: Circular-arc cam.
Pulsion: ¼ (270.7 mm.) = 10.66 in. per sec.
Suction: ¾ (90.2 mm.) = 3.55 in. per sec.

On mesh.....	12	20.	40.	60.	80.	100.	thro' 100.	Total
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	11.8	31.8	30.2	11.0	5.0	2.2	5.2	97.2
B.	20.0	20.0	25.0	30.0	35.0	40.0	50.0	
C.	2.4	6.4	7.5	3.3	1.7	0.8	2.6	24.7

Percentage of sphalerite in concentrates: 24.7.

Ratio of concentration based on original feed: 2.47.

Remarks—The bedding pulsated very violently, and after the jig was stopped it was found that the surface of the ore-column was 1.5 in. below the tailings-dam.

TEST 42.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind: Circular-arc cam.
Pulsion: ¾ (90.2 mm.) = 3.55 in. per sec.
Suction: ¼ (270.7 mm.) = 10.66 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	3.6	14.1	36.5	19.2	9.5	4.5	12.2	99.6
B.	60.0	65.0	35.0	30.0	35.0	30.0	40.0	
C.	2.1	9.1	12.7	5.7	3.3	1.4	5.0	39.3

Percentage of sphalerite in concentrates: 39.3.

Ratio of concentration based on original feed: 3.93.

Remarks.—The bedding-grains were carried up from bottom to top, circulating in that way as by convection-currents. The ore-column was in active agitation, and the bedding and the ore were not separated by a clearly defined and horizontal line.

Test 43.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160 Length, 1 in. (25.4 mm.).
Kind : Involute cam.
Pulsion : $\frac{1}{3}$ (203.2 mm.) = 8 in. per sec
Suction : $\frac{2}{3}$ (101.6 mm.) = 4 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	7.6	26.5	34.5	13.7	6.7	3.1	8.1	100.2
B.	25.0	35.0	25.0	25.0	35.0	30.0	40.0	
C.	1.9	9.2	8.6	3.4	2.2	0.9	3.2	29.4

Percentage of sphalerite in concentrates : 29.4.

Ratio of concentration based on original feed : 2.94.

Remarks.—The jig-bed pulsated violently. The bedding did not tend to move in convection-currents, as in Test 42. Between the bedding and the ore-column was a very active zone 0.5 in wide, in which the mineral particles moved in all directions and with great rapidity.

Test 44.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min , 160 Length, 1 in. (25.4 mm.).
Kind : Involute cam.
Pulsion : $\frac{2}{3}$ (101.6 mm.) = 4 in. per sec.
Suction : $\frac{1}{3}$ (203.2 mm.) = 8 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	3.4	17.5	40.1	17.1	8.7	4.0	9.2	100.0
B.	85.0	60.0	30.0	25.0	35.0	30.0	40.0	
C.	3.0	10.5	12.0	4.2	2.9	1.2	3.8	37.6

Percentage of sphalerite in concentrates : 37.6

Ratio of concentration based on original feed : 3.76.

Remarks.—The movement of the jig-bed was very similar to Test 42. The bedding-grains were not only carried from the bottom of the bedding-column itself, but many rose to the top of the ore-column, and a few of the lightest were carried off with the tailings. The grains of quartz could be seen very plainly rolling down with the larger bedding-grains and being carried into the hutch.

Test 45.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind : Eccentric.
Pulsion and Suction : $\frac{1}{2}$ (135.5 mm.) = 5.33 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	5.3	17.0	32.2	18.0	9.2	4.7	13.3	99.7
B.	85.0	80.0	45.0	40.0	35.0	40.0	45.0	
C.	4.6	13.6	14.4	7.2	3.3	1.8	5.8	50.7

Percentage of sphalerite in concentrates : 50.7.

Ratio of concentration based on original feed : 5.07.

Remarks.—Both the bedding and the ore-column pulsated regularly. Each formed distinct and well-defined layers. The jig worked very rapidly.

TEST 46.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, ½ in. (12.7 mm.).
Kind : Eccentric.
Pulsion and Suction ½ (67.7 mm.) = 2.66 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	3.4	15.7	29.7	19.0	11.4	5.8	15.0	100.0
B.	100.0	90.0	50.0	35.0	30.0	30.0	40.0	
C.	3.4	14.4	15.0	6.6	3.3	1.8	6.0	50.5

Percentage of sphalerite in concentrates : 50.5.

Ratio of concentration based on original feed : 5.05.

Remarks.—The upper half to three-fourths of the bedding pulsated regularly, the bottom grains were almost stationary. The lower part of the ore-column consisted of the largest particles of quartz, with smaller and smaller grains to the top.

TEST 47.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, ½ in. (12.7 mm.).
Kind : Circular-arc cam.
Pulsion : ¼ (135.5 mm.) = 5.33 in. per sec.
Suction : ¾ (45.2 mm.) = 1.77 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	7.0	19.8	34.0	18.8	8.5	3.7	8.0	99.8
B.	60.0	55.0	30.0	25.0	30.0	30.0	40.0	
C.	4.2	11.0	10.2	4.7	2.5	1.2	3.2	37.0

Percentage of sphalerite in concentrates : 37.0.

Ratio of concentration based on original feed : 3.70.

Remarks.—The entire bed moved *en masse*, the top of the column having a longer amplitude of vibration and requiring a longer time for its completion than the grains nearer the bottom. The jig worked rapidly.

TEST 48.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, ½ in. (12.7 mm.).
Kind : Circular-arc cam.
Pulsion : ¾ (45.2 mm.) = 1.77 in. per sec.
Suction : ¼ (135.5 mm.) = 5.33 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	1.1	7.0	35.0	24.6	12.2	5.1	15.0	100.0
B.	90.0	75.0	30.0	25.0	30.0	30.0	35.0	
C.	1.0	5.2	10.5	6.2	3.6	1.5	5.2	33.2

Percentage of sphalerite in concentrates : 33.2.

Ratio of concentration based on original feed : 3.32.

Remarks.—The bedding pulsated, but not regularly, and tended to thicken in the middle and thin down at the ends. The grains at the bottom of the ore-column were in very active agitation, but it was found that these grains were really describing two distinct orbits.

Test 49.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke: Cam shaft rev. per min., 160. Length, ½ in. (12.7 mm.).
Kind: Involute cam.
Pulsion: ⅓ (101.6 mm.) = 4 in. per sec.
Suction: ⅔ (50.8 mm.) = 2 in. per sec.

On mesh.... / Size in mm..	12. / 1.66	20. / 0.97	40. / 0.42	60. / 0.26	80. / 0.21	100. / 0.16	thro' 100. / 0.16	Total.
A.	9.6	20.0	31.0	18.5	8.5	3.7	7.3	98.6
B.	50.0	65.0	35.0	25.0	30.0	30.0	40.0	
C.	4.8	13.0	10.8	4.2	2.5	1.1	2.8	39.2

Percentage of sphalerite in concentrates: 39.2.

Ratio of concentration based on original feed: 3.92.

Remarks.—The upper two-thirds of the bedding and the entire ore-column pulsated regularly. As noted before, the grains nearest the top had a longer amplitude of vibration and required a longer time to complete it. The lower one-third of the bedding was quite stationary.

Test 50.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ½ in. (12.7 mm.).
Kind: Involute cam.
Pulsion: ⅔ (50.8 mm.) = 2 in. per sec.
Suction: ⅓ (101.6 mm.) = 4 in. per sec.

On mesh.... / Size in mm..	12. / 1.66	20. / 0.97	40. / 0.42	60. / 0.26	80. / 0.21	100. / 0.16	thro' 100. / 0.16	Total.
A.	0.8	8.7	41.4	22.0	10.0	4.8	11.6	99.3
B.	100.0	65.0	25.0	25.0	25.0	35.0	40.0	
C.	0.8	5.8	10.2	5.5	2.5	1.6	4.6	31.0

Percentage of sphalerite in concentrates: 31.0.

Ratio of concentration based on original feed: 3.1.

Remarks.—The bedding pulsated slightly, and the grains shifted positions as in convection-currents. A zone between the bedding and the ore-column moved much as noted in Test 40. The ore-column above this zone pulsated regularly, although the ore-column was not very mobile.

Test 51.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.).
Kind: Circular-arc cam.
Pulsion: ¼ (67.7 mm.) = 2.66 in. per sec.
Suction: ¾ (22.5 mm.) = 0.88 in. per sec.

On mesh..... / Size in mm..	12. / 1.66	20. / 0.97	40. / 0.42	60. / 0.26	80. / 0.21	100. / 0.16	thro' 100. / 0.16	Total.
A.	1.4	9.5	44.5	22.2	9.4	4.6	8.0	99.6
B.	90.0	80.0	25.0	25.0	35.0	30.0	35.0	
C.	1.2	7.6	11.0	5.5	3.2	1.5	2.8	32.8

Percentage of sphalerite in concentrates: 32.8.

Ratio of concentration based on original feed: 3.28.

Remarks.—The bedding and with it the ore-column pulsated *en masse.* Taking the entire column of bedding and ore as a whole, the top had a much longer amplitude of vibration, and required a longer time in which to complete it.

TEST 52.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.).
Kind : Circular-arc cam.
Pulsion : ¾ (22.5 mm.) = 0.88 in. per sec.
Suction : ¼ (67.7 mm.) = 2.66 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	2.0	11.6	31.8	22.7	11.6	5.5	14.6	99.8
B.	100.0	95.0	45.0	35.0	35.0	35.0	35.0	
C.	2.0	11.0	14.4	8.0	4.2	1.6	4.9	46.1

Percentage of sphalerite in concentrates : 46.1.

Ratio of concentration based on original feed : 4.61.

Remarks.—Movement of jig-bed very similar to that of Test 48, but to a less extent.

TEST 53.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.).
Kind : Involute cam.
Pulsion : ⅓ (50.8 mm.) = 2 in. per sec.
Suction : ⅔ (25.4 mm.) ≐ 1 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	0.6	9.8	30.0	23.8	13.0	7.5	14.8	99.5
B.	100.0	90.0	55.0	40.0	35.0	30.0	35.0	
C.	0.6	9.0	16.5	9 5	4.5	2.1	5.2	47.4

Percentage of sphalerite in concentrates : 47.4.

Ratio of concentration based on original feed : 4.74.

Remarks.—The bedding pulsated in the upper third and half, and was quite mobile as well. The lower part, however, was stationary. The line between bedding and ore was horizontal and straight. The ore-column pulsated regularly—the top for a greater distance, and for a longer time, as before.

TEST 54.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.).
Kind : Involute cam.
Pulsion : ⅔ (25.4 mm.) = 1 in. per sec.
Suction : ⅓ (50.8 mm.) = 2 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	0.8	5.4	31.2	28.6	13.5	6.7	14.7	100.9
B.	100.0	90.0	50.0	30.0	35.0	30.0	35.0	
C.	0.8	4.8	15.5	8.6	4.5	2.1	4.9	41.2

Percentage of sphalerite in concentrates : 41.2.

Ratio of concentration based on original feed : 4.12.

Remarks.—The entire bedding was practically stationary, did not pulsate, nor was it mobile. The interstitial spaces in the upper part of bedding filled with grains of sphalerite. The ore-column pulsated *en masse* and was fairly mobile.

TEST 55.—*Sphalerite* 10, *Quartz* 90 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, $\frac{1}{4}$ in. (6.35 mm.).
Kind : Eccentric.
Pulsion and Suction : $\frac{1}{2}$ (33.9 mm.) = 1.33 in. per sec.

On mesh..... Size in mm..	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	thro' 100. 0.16	Total.
A.	0.4	7.7	29.2	19.6	15.0	8.2	19.5	99.6
B.	90.0	95.0	70.0	45.0	40.0	35.0	35.0	
C.	0.4	7.3	20.6	9.0	6.0	2.8	6.6	52.7

Percentage of sphalerite in concentrates : 52.7.

Ratio of concentration based on original feed : 5.27.

Remarks.—The upper third of the bedding was mobile, but the lower two-thirds was quite fixed. The ore-column pulsated regularly, together with the upper third of bedding. The line between the ore-column and the bedding was clearly marked.

TEST 61.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind : Circular-arc cam.
Pulsion : $\frac{1}{4}$ (270.7 mm.) = 10.66 in. per sec.
Suction : $\frac{3}{4}$ (90.2 mm.) = 3.55 in. per sec.

On mesh..... Size in mm..	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	thro' 100. 0.16	Total.
A.	6.3	28.2	33.6	12.6	6.0	2.7	9.8	99.2
B.	45.0	35.0	30.0	30.0	35.0	40.0	50.0	
C.	2.7	9.8	10.0	3.8	2.1	1.0	4.5	33.9

Percentage of sphalerite in concentrates : 33.9.

Ratio of concentration based on original feed : 1.7.

Remarks.—The entire jig-bed pulsated very violently. The feed was very fast, a large amount of hutch-work was made, and the tailings contained considerable fine mineral. The fine quartz could be seen sifting through the bedding.

TEST 62.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind : Circular-arc cam.
Pulsion : $\frac{3}{4}$ (90.2 mm.) = 3.55 in. per sec.
Suction : $\frac{1}{4}$ (270.7 mm.) = 10.66 in. per sec.

On mesh..... Size in mm..	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	thro' 100. 0.16	Total.
A.	1.9	13.2	38.0	18.3	9.7	4.6	14.0	99.7
B.	90.0	75.0	35.0	40.0	40.0	50.0	50.0	
C.	1.8	9.7	13.3	7.4	3.8	2.3	7.0	45.3

Percentage of sphalerite in concentrates : 45.2.

Ratio of concentration based on original feed : 2.26.

Remarks.—Behavior of jig-bed similar to Test 41.

Test 63.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind : Involute cam.
Pulsion : $\frac{1}{3}$ (203.2 mm.) = 8 in. per sec.
Suction : $\frac{2}{3}$ (101.6 mm.) = 4 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	4.8	21.5	36.8	15.1	7.8	3.3	10.2	99.5
B.	70.0	50.0	35.0	40.0	45.0	50.0	60.0	
C.	3.3	10.7	12.9	6.0	3.4	1.6	6.0	43.9

Percentage of sphalerite in concentrates : 43.9.
Ratio of concentration based on original feed : 2.20.
Remarks.—Behavior of jig-bed similar to Test 43.

Test 64.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind : Involute cam.
Pulsion : $\frac{2}{3}$ (101.6 mm.) = 4 in. per sec.
Suction : $\frac{1}{3}$ (203.2 mm.) = 8 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	2.3	17.2	37.8	17.3	8.5	4.1	12.8	100.0
B.	85.0	45.0	35.0	40.0	40.0	50.0	55.0	
C.	1.9	7.6	13.1	6.8	3.4	2.0	6.8	41.6

Percentage of sphalerite in concentrates : 41.6.
Ratio of concentration based on original feed : 2.08.
Remarks —Movement of jig-bed similar to Test 44.

Test 65.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, 1 in. (25.4 mm.).
Kind : Eccentric.
Pulsion and Suction : $\frac{1}{2}$ (135.5 mm.) = 5.33 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	2.5	14.2	34.6	18.6	10.0	4.5	15.0	99.4
B.	90.0	80.0	50.0	40.0	45.0	50.0	60.0	
C.	2.2	11.2	17.2	7.4	4.5	2.2	9.0	53.7

Percentage of sphalerite in concentrates : 53.7.
Ratio of concentration based on original feed : 2.7.
Remarks.—Movement of jig-bed similar to Test 45.

Test 66.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke : Cam-shaft rev. per min., 160. Length, $\frac{1}{2}$ in. (12.7 mm.).
Kind : Eccentric.
Pulsion and Suction : $\frac{1}{2}$ (67.7 mm.) = 2.66 in. per sec.

On mesh.....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	2.5	12.4	33.0	19.0	11.0	4.9	17.2	100.0
B.	90.0	85.0	60.0	45.0	45.0	50.0	50.0	
C.	2.2	10.5	20.0	8.5	5.0	2.5	8.6	57.3

Percentage of sphalerite in concentrates: 57.3.

Ratio of concentration based on original feed: 2.8.

Remarks.—Movement of jig-bed similar to Test 46.

TEST 67.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ½ in. (12.7 mm.).
Kind: Circular-arc cam.

Pulsion: ¾ (135.5 mm.) = 5.33 in. per sec.

Suction: ¼ (45.2 mm.) = 1.77 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	6.1	16.3	32.4	16.9	8.7	4.0	14.2	98.6
B.	65.0	60.0	45.0	35.0	40.0	45.0	50.0	
C.	3.9	9.6	14.6	6.0	3.4	1.8	7.1	46.4

Percentage of sphalerite in concentrates: 46.4.

Ratio of concentration based on original feed: 2.32.

Remarks.—The bedding and the ore-column pulsated, and the bottom grains of bedding much more than in Test 66.

TEST 68.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ½ in. (12.7 mm.).
Kind: Circular-arc cam.

Pulsion: ¼ (45.2 mm.) = 1.77 in. per sec.

Suction: ¾ (135.5 mm.) = 5.33 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	1.2	8.1	36.4	21.6	11.2	5.6	16.5	100.6
B.	95.0	80.0	50.0	40.0	40.0	45.0	50.0	
C.	1.1	6.4	18.2	8.6	4.4	2.5	8.2	49.4

Percentage of sphalerite in concentrates: 49.4.

Ratio of concentration based on original feed: 2.47.

Remarks.—Movement of jig-bed similar to Test 48.

TEST 69.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ½ in. (12.7 mm.).
Kind: Involute cam.

Pulsion: ⅓ (101.6 mm.) = 4 in. per sec.

Suction: ⅔ (50.8 mm.) = 2 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	5.2	18.2	32.7	17.7	9.2	4.1	12.5	99.6
B.	70.0	75.0	45.0	45.0	50.0	50.0	55.0	
C.	3.5	13.5	14.8	7.9	4.6	2.0	6.8	53.1

Percentage of sphalerite in concentrates: 53.1.

Ratio of concentration based on original feed: 2.65.

Remarks.—The entire jig-bed moved *en masse*, and was very mobile. As in all cases of this kind, the upper part of the ore-column had a longer amplitude of vibration and required a longer time in which to complete it than the grains (whether bedding or ore) nearer the bottom.

Test 70.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ½ in. (12.7 mm.).
Kind: Involute cam.
Pulsion: ⅔ (50.8 mm.) = 2 in. per sec.
Suction: ⅓ (101.6 mm.) = 4 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	1.1	8.7	40.6	20.8	10.5	4.5	13.7	99.9
B.	95.0	80.0	45.0	35.0	40.0	50.0	60.0	
C.	1.0	6.8	16.2	7.4	4.2	2.2	8.1	45.9

Percentage of sphalerite in concentrates: 45.9.
Ratio of concentration based on original feed: 2.29.
Remarks.—Movement of jig-bed similar to Test 50.

Test 71.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.).
Kind: Circular-arc cam.
Pulsion: ¼ (67.7 mm.) = 2.66 in. per sec.
Suction: ¾ (22.5 mm.) = 0.88 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	1.1	12.0	38.5	22.0	10.0	4.6	11.2	99.4
B.	95.0	80.0	40.0	35.0	45.0	50.0	55.0	
C.	1.0	9.6	14.9	7.7	4.7	2.3	6.0	46.2

Percentage of sphalerite in concentrates: 46.2.
Ratio of concentration based on original feed: 2.31.
Remarks.—Movement of jig-bed similar to Test 51.

Test 72.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.).
Kind: Circular-arc cam.
Pulsion: ¾ (22.5 mm.) = 0.88 in. per sec.
Suction: ¼ (67.7 mm.) = 2.66 in. per sec.

On mesh....	12.	20.	40.	60.	80.	100.	thro' 100.	Total.
Size in mm..	1.66	0.97	0.42	0.26	0.21	0.16	0.16	
A.	1.8	10.6	31.2	22.2	12.4	6.4	15.2	99.8
B.	100.0	95.0	70.0	50.0	45.0	50.0	60.0	
C.	1.8	9.9	21.7	11.1	5.6	3.8	9.0	62.9

Percentage of sphalerite in concentrates: 62.9.
Ratio of concentration based on original feed: 3.14.
Remarks.—The entire mass except the lower part of the bedding pulsated *en masse*, and the ore-column seemed quite mobile.

Test 73.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.).
Kind: Involute cam.
Pulsion: ½ (50.8 mm.) = 2 in. per sec.
Suction: ⅜ (25.4 mm.) = 1 in. per sec.

On mesh..... Size in mm..	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	thro'100. 0.16	Total.
A.	1.3	8.7	27.2	20.6	14.1	7.1	20.8	99.8
B.	100.0	100.0	80.0	50.0	50.0	55.0	60.0	
C.	1.3	8.7	21.6	10.3	7.0	3.8	12.6	65.3

Percentage of sphalerite in concentrates: 65.3.

Ratio of concentration based on original feed: 3.26.

Remarks.—The upper two-thirds of bedding and the entire ore-column pulsated. Ore-column mobile.

Test 74.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.).
Kind: Involute cam.
Pulsion: ⅜ (25.4 mm.) = 1 in. per sec.
Suction: ½ (50.8 mm.) = 2 in. per sec.

On mesh..... Size in mm..	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	thro'100. 0.16	Total.
A.	0.9	6.5	24.5	20.6	15.5	7.9	24.1	100.0
B.	100.0	100.0	85.0	65.0	55.0	60.0	60.0	
C.	0.9	6.5	20.9	13.3	8.5	4.8	14.4	69.3

Percentage of sphalerite in concentrates: 69.3.

Ratio of concentration based on original feed: 3.46.

Remarks.—The upper third of bedding together with the ore-bed pulsated *en masse.* The lower two-thirds of bedding was quite fixed in position. The top of ore-column, as before, had a longer amplitude.

Test 75.—*Sphalerite* 20, *Quartz* 80 *per cent.*

Stroke: Cam-shaft rev. per min., 160. Length, ¼ in. (6.35 mm.)
Kind: Eccentric.
Pulsion and Suction: ½ (33.9 mm.) = 1.33 in. per sec.

On mesh..... Size in mm..	12. 1.66	20. 0.97	40. 0.42	60. 0.26	80. 0.21	100. 0.16	thro'100. 0.16	Total.
A.	0.2	4.2	29.1	20.2	13.8	7.1	24.8	99.4
B.	90.0	90.0	75.0	65.0	55.0	60.0	60.0	
C.	0.2	3.8	21.8	13.0	7.4	4.2	15.0	65.4

Percentage of sphalerite in concentrates: 65.4.

Ratio of concentration based on original feed: 3.27.

Remarks.—The upper third of bedding together with the ore-column pulsated *en masse.* The lower two-thirds of bedding scarcely moved. The interstitial spaces of the bedding, as with all experiments with the short stroke, filled with mineral.

5. *Discussion of Results.*

It is evident that in a machine so simple as the jig there are a number of variables, and a series of tests may therefore be

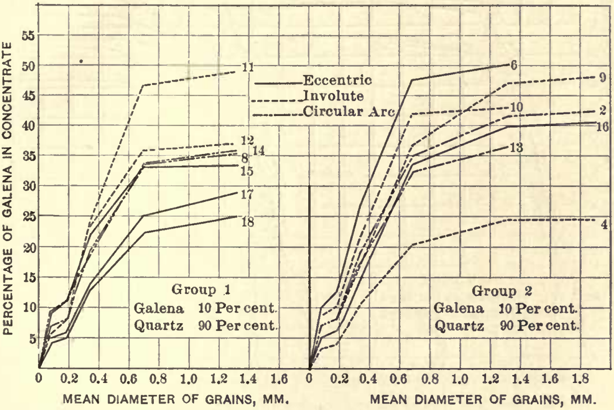


FIG. 6.—CHART OF RESULTS OF GROUPS 1 AND 2 OF CLASS I.

classified according to some one of them. For purposes of discussion, however, the tests that have been conducted are grouped

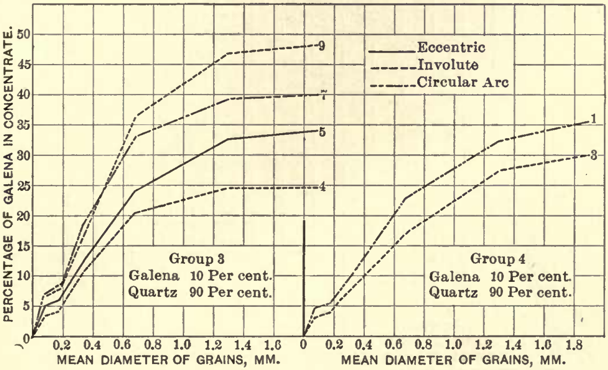


FIG. 7.—CHART OF RESULTS OF GROUPS 3 AND 4 OF CLASS I.

according to the velocity of the rising current of water, or pulsion-currents, as measured by the mean piston-speed. Figs. 6

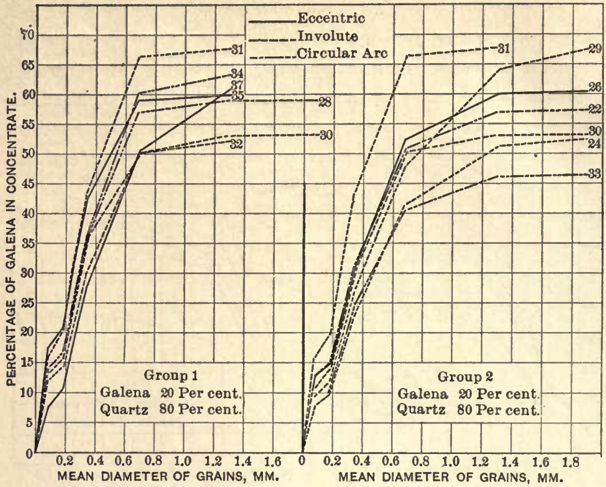


FIG. 8.—CHART OF RESULTS OF GROUPS 1 AND 2 OF CLASS II.

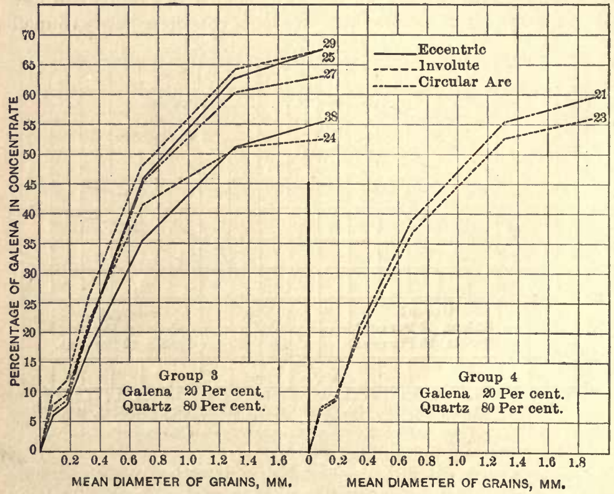


FIG. 9.—CHART OF RESULTS OF GROUPS 3 AND 4 OF CLASS II.

to 13, inclusive, show graphically the results given in row *C*, under each of the experiments, calculated for the mean diame-

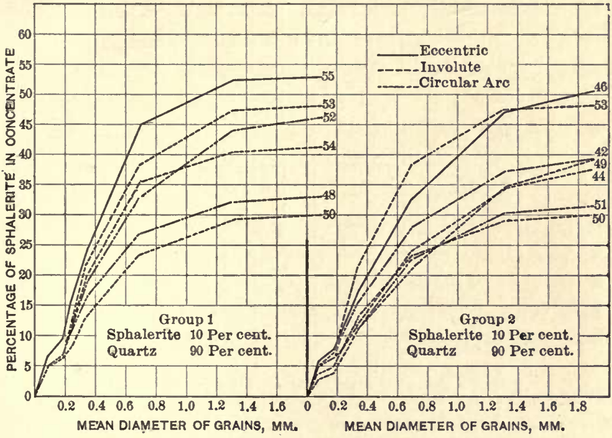


FIG. 10.—CHART OF RESULTS OF GROUPS 1 AND 2 OF CLASS III.

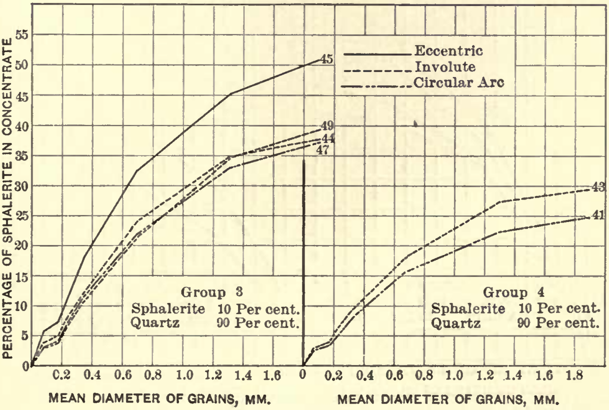


FIG. 11.—CHART OF RESULTS OF GROUPS 3 AND 4 OF CLASS III.

ter of the material. Since all material treated on the jig passed through a screen having a square hole, the mean length of the

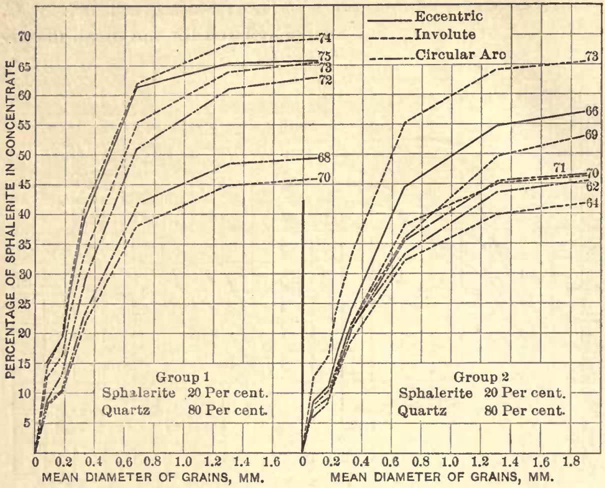


FIG. 12.—CHART OF RESULTS OF GROUPS 1 AND 2 OF CLASS IV.

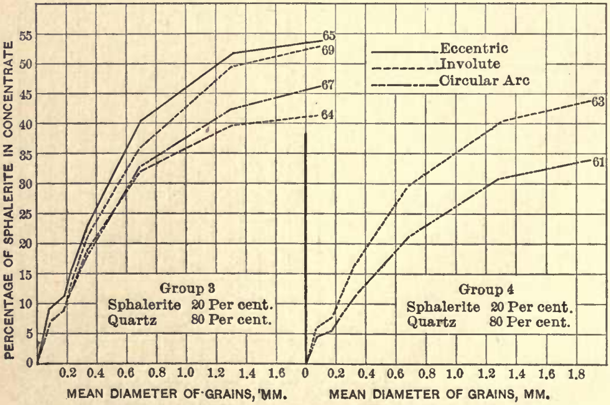


FIG. 13.—CHART OF RESULTS OF GROUPS 3 AND 4 OF CLASS IV.

sides of which was equal to 2.136 mm., and from that as a maximum to the very finest dust, it has been assumed that the

mean diameter of the grain caught on the 1.66-mm. screen is $(2.136 + 1.66) \div 2 = 1.90$ mm.; those passing the 1.66-mm. screen and caught on the 0.97-mm. screen, have a mean diameter of $(1.66 + 0.97) \div 2 = 1.31$ mm., and so on for all the sizes; and, finally, that the material passing the 0.16-mm. screen (the finest used in these tests) had a mean diameter of 0.08 mm. In the curves shown in Figs. 6 to 13 the diameter of the grain has been plotted along the X axis, and the weight of pure mineral (galena or sphalerite) on each screen-size, as given in the record of the tests, laid off on the Y axis. The points thus located have been joined by three classes of lines: the solid lines in all cases represent the results obtained in the tests made with the eccentric cam; the dotted lines, tests with the involute cam; and, finally, the broken lines, tests with the circular-arc cams.

The velocities of the pulsion- or rising-currents, as measured above, have been divided, on purely arbitrary grounds, into four groups: (1) velocities of pulsion 2 in. (50.8 mm.) per sec. and less; (2) velocities of pulsion from 2 to 4 in. (50.8 to 101.6 mm.) per sec.; (3) velocities of pulsion from 4 to 6 in. (101.6 to 152.4 mm.) per sec.; (4) velocities of pulsion from 6 to 10.66 in. (152.4 to 271 mm.) per sec. With this arrangement it has so happened that in nearly every case the tests with the involute cam are plotted in two groups. The experiments with the eccentric and circular-arc cams occur once only in each group. Since each pair of minerals has been run with 10 and with 20 per cent. of either galena or blende, two classes are to be distinguished. In all cases under discussion, Classes I. and III. will refer to mixtures containing 10 per cent., and Classes II. and IV. to mixtures with 20 per cent. of the heavy mineral.

In order to facilitate reference, the following classification is given:

Class I. Galena and Quartz. Galena 10, Quartz 90 per cent.

Group 1. Velocities of pulsion from 0 to 2 in. (0 to 50.8 mm.) per sec.

Tests 8, 11, 12, 14, 15, 17, 18.

Group 2. Velocities of pulsion from 2 to 4 in. (50.8 to 101.6 mm.) per sec.

Tests 2, 4, 6, 9, 10, 12, 16.

Group 3. Velocities of pulsion from 4 to 6 in. (101.6 to 152.4 mm.) per sec.

Tests 4, 5, 7, 9.

Group 4. Velocities of pulsion from 6 to 10.66 in. (152.4 to 271 mm.) per sec.

Tests 1, 3.

Class II. Galena and Quartz. Galena 20, Quartz 80 per cent.

Group 1. Velocities of pulsion from 0 to 2 in. (0 to 50.8 mm.) per sec.

Tests 28, 30, 31, 32, 34, 35, 37.

Group 2. Velocities of pulsion from 2 to 4 in. (50.8 to 101.6 mm.) per sec.

Tests 22, 24, 26, 29, 30, 31, 33.

Group 3. Velocities of pulsion from 4 to 6 in. (101.6 to 152.4 mm.) per sec.

Tests 24, 25, 27, 29, 38.

Group 4. Velocities of pulsion from 6 to 10.66 in. (152.4 to 271 mm.) per sec.

Tests 21, 23.

Class III. Sphalerite and Quartz. Sphalerite 10, Quartz 90 per cent.

Group 1. Velocities of pulsion from 0 to 2 in. (0 to 50.8 mm.) per sec.

Tests 48, 50, 52, 53, 54, 55.

Group 2. Velocities of pulsion from 2 to 4 in. (50.8 to 101.6 mm.) per sec.

Tests 42, 44, 46, 49, 50, 51, 53.

Group 3. Velocities of pulsion from 4 to 6 in. (101.6 to 152.4 mm.) per sec.

Tests 44, 45, 47, 49.

Group 4. Velocities of pulsion from 6 to 10.66 in. (152.4 to 271 mm.) per sec.

Tests 41, 43.

Class IV. Sphalerite and Quartz. Sphalerite 20, Quartz 80 per cent.

Group 1. Velocities of pulsion from 0 to 2 in. (0 to 50.8 mm.) per sec.

Tests 68, 70, 72, 73, 74, 75.

Group 2. Velocities of pulsion from 2 to 4 in. (50.8 to 101.6 mm.) per sec.

Tests 62, 64, 66, 69, 70, 71, 73.

Group 3. Velocities of pulsion from 4 to 6 in. (101.6 to 152.4 mm.) per sec.

Tests 64, 65, 67, 69.

Group 4. Velocities of pulsion from 6 to 10.66 in. (152.4 to 271 mm.) per sec.

Tests 61, 63.

Class I., Group 1. Galena, 10 per cent. The two lowest ratios of concentration were obtained with two tests with eccentric cam, using a short stroke and a high frequency in Tests 17 and 18; and of these two, Test 18, with only a $\frac{1}{16}$-in. stroke and 400 strokes per min., yields the lowest ratio of the series. An examination of the screen-analysis shows a marked difference between Tests 18 and 15; the longer and slower stroke has caused a larger percentage of the finest size to pass into the hutch; but the shorter and more rapid stroke has increased the percentage of material between 1.31 and 0.69 mm. in the concentrate. In this case, at least, piston-speed does not determine whether the jig-bed will be pulsated, or the proportions of coarse and fine material carried into the hutch.

The highest ratio of concentration is clearly with the involute cam, Test 11, with a pulsion-velocity of 2 in. (50.8 mm.) and suction-velocity of 1 in. (25.4 mm.) per sec. A good catch of fine material is made, and the three largest sizes are of good proportions as to weight and mineral-content—the sudden drop in value for particles of 0.34 mm. diameter should be noted.

Tests 8, 12, 14, and 15 represent the three types of strokes. The weak pulsion and strong suction of Tests 8 and 14 have produced results very similar to those of the eccentric. This style of cam, therefore, between the limits of this group, is not more efficient than the eccentric. In none of the experiments of this group has any material of mean diameter 1.90 mm. been carried through the sieve and into the hutch. It cannot be said that strong suction is superior to moderate suction in saving the fines.

Class I., Group 2. The minimum ratio of concentration is that with the involute cam, Test 4 representing the highest

limit of velocity of pulsion for this group and very strong suction. The strong suction, however, has not resulted in increasing the proportion of fines, probably owing to the fact that there is also a rather high pulsion-velocity. The conditions in this test have been favorable for the recovery of grains of mean diameter of 0.69 mm. (on 0.42-mm. screen). The highest ratio of concentration is obtained in Test 6, an eccentric, with velocity of pulsion and suction 2.66 in. (67.7 mm.) per sec. Test 10, an involute cam, with slow pulsion and rapid suction, gives results similar to Test 6. Test 9 gives very good results, with high pulsion and slow suction, just the reverse of Test 10. In this latter case the strong pulsion is clearly an advantage, resulting in almost as good a saving of fines, and a much larger and cleaner product on the large sizes. Test 4, with circular-arc cam, and Test 16, with eccentric cam, give results quite close. Why Test 4 should differ so materially from Test 2 is not easy to explain. Tests 10 and 4 represent the velocity-limits of the group and show marked differences in results; and in Tests 4 and 9, with the same velocity of pulsion, but different suction-velocity, the strong suction has produced a much smaller percentage of the finest size and contains less galena, although the strong suction has been very effective in drawing material having a mean diameter of 0.69 mm. into the hutch. The eccentric, with short stroke and high frequency, Test 16, gives a low ratio of concentration. In all cases only a small catch is made with sizes larger than about 1 mm., and at least from 75 to 95 per cent. of the mineral saved in the hutch is of a diameter of 0.69 mm. or less.

In this group the same pulsion-velocity but variable suction-velocity give different results; the high suction-velocity is not of any distinct advantage in increasing the catch of fines or in enriching any of the sizes. The eccentric at proper rotative and pulsion-speeds yields results equal and in most cases superior to an accelerated and retarded stroke.

Class I., Group 3. In this group of four experiments, Test 4, which was also placed with group 2 of this class, and occupied the lowest position, is also the lowest in this group. The highest ratio of concentration is found in Test 9, an involute cam with the same pulsion-velocity as Test 4, but only one-fourth the suction-velocity. As noted under group 2, the

strong suction has resulted in producing a smaller amount of the finest size, and in a decreased percentage of galena in all the sizes. The intermediate positions are marked by an eccentric cam, Test 5, and a circular-arc cam, Test 7, and with the same velocity of pulsion. The strong pulsion and weak suction has resulted in a larger saving of the fine material than in the case of the eccentric, and a somewhat higher ratio of concentration.

It appears, therefore, that in this group the involute cam with strong pulsion and weak suction is the most efficient in producing a high concentrate, and the reverse of these conditions the least efficient; that the circular-arc cam, Test 7, with strong pulsion and weak suction, is somewhat more efficient than the eccentric; and that the same velocities of pulsion yield different results.

It will be noted, also, that all the tests in this group produced some of the coarsest size, and those of strong pulsion and weak suction the largest amount. In comparing this group with group 2 of this series, we find that the maximum ratio has been passed, and that velocities of pulsion more than 4 in. (101.6 mm.) per sec., with the size of material jigged, should not be exceeded.

Class I., Group 4. Only two experiments occur in this group, Tests 1 and 3. Length of stroke in each case 1 in. It appears that the circular-arc cam with the highest velocity of pulsion and least velocity of suction gives a little higher ratio of concentration, but that the results are very much the same. The proper limit for pulsion-velocities has long since been exceeded. Comparing Tests 3 and 4 in the same way, it is found that strong pulsion and weak suction produced practically the same percentages of sieve-sizes, but with strong suction the percentage of heavy material is much reduced. Even with these high velocities of pulsion, a strong suction is not an advantage, in increasing either the amount of fine material drawn into the hutch or the percentage of heavy mineral.

Class II., Group 1. Galena, 20 per cent. Of the seven tests in the group, the involute cam, Test 31, with velocity of pulsion at the maximum limit of the group, gives the highest ratio of concentration. The same was true under Class I. The final minimum ratio is indicated by the reciprocal of Test 31, with

weak pulsion and strong suction. With material up to 0.69 mm. in diameter, the eccentric with short and rapid stroke gives the lowest ratio in Test 37, while at the same piston-speed at twice the length of stroke and half the number of rev. per min., the values are very close to the maximum in Test 35.

The involute cam in Test 30, with weak pulsion and strong suction, produces similar results but at different velocities, but at the same ratio to Test 32. In this case the strongest suction has drawn a larger percentage of the fine stuff into the hutch, but has not enriched it.

The two circular-arc cams, Tests 28 and 34, with weak pulsion and strong suction, give similar results, in which about 30 per cent. of the hutch-product passes through a 100-mesh (0.16 mm.) sieve. But again, in Test 31, with the involute cam, strong pulsion and weak suction, a larger percentage of fine material is drawn into the hutch. The eccentric gives about the same percentage of fines as in Test 31.

It may be said for this group that the eccentric at the proper length and rotative velocity gives excellent results, and is generally superior to an accelerated or retarded stroke. The same pulsion-velocities give different results.

Class II., Group 2. The minimum ratio of concentration is indicated by the circular-arc cam, Test 33, with strong pulsion and weak suction. The maximum is attained with an involute cam, Test 31, with rapid pulsion and weak suction. The involute cam has already been considered under the first group. Test 29, also an involute, under the same conditions, gives good ratios, but the higher pulsion-velocity results in a smaller saving of the very fine material; larger sizes appear more abundantly in the hutch, however. Tests 24 and 30, involute cams with suction in excess of pulsion, give final results that are very close, but the strongest suction, Test 24, yields relatively less fine and more coarse material than the weaker suction.

It will be noted, further, that with the exception of Test 31, some stuff larger than 1.66 mm. is found in all the products. The circular-arc cam with very high velocity of suction has produced a relatively high percentage of the finest size. The eccentric, Test 26, gives good average results—a large percentage by weight of the finest, and containing at least an average percentage of galena. With the exception of Tests 29

and 31, the five other tests are, in general, much the same. Both of these tests have been classed in other groups. Of the three highest ratios of concentration, two have low suction-velocity and the third has equal pulsion and suction.

Class II., Group 3. Of these five tests the minimum is found in Test 24, repeating the conditions of Test 4. It will be noted, however, that until the size next the largest is reached, the lowest ratio is indicated by the eccentric, Test 38, with short stroke and high rotative speed. Test 29, involute cam, strong pulsion and weak suction, and Test 25, eccentric, at the same piston-speed as Test 38, give almost the same final results.

The circular-arc cam, Test 27, strong pulsion and weak suction, produces results very similar to those of Tests 25 and 29.

In all cases with these high pulsion-velocities, more material having a diameter of 1.31 and 1.90 mm., and correspondingly less of the finer sizes, have been obtained. The advantages of high suction-velocity over those of pulsion are not apparent.

Class II., Group 4. An examination of the two tests in this group indicates at once a close correspondence. The maximum limit for pulsion-velocity has been passed, but it appears that with the richer feed these velocities vary between considerably wider limits than with the poorer material.

In general, it may be said for all the tests, that for each condition under which jigging takes place, certain sizes—20- or 40-mesh (0.97 or 0.42 mm.)—are very rich, and then on smaller sizes a very violent drop in the percentage of galena takes place. This will be noticed for all tests on galena and blende as well. Also, that moderate suction and stronger pulsion give better results than the reverse. The strong pulsion usually results in a larger yield of the coarser sizes of higher percentage in mineral, and the fines are saved almost equally as well. In most cases the eccentric, at the proper length of stroke and rotative speed, is equal and usually superior to accelerated or retarded stroke; but when the stroke becomes too short and the rotative speed high, the ratio falls off. Observations on the behavior of the bed under these conditions showed that the bedding and ore-column pulsated, although at the same piston-speed with the longer stroke no movement in the bedding took place. This indicates that, with very sudden impulses to the ore-column, the water acts more like a solid than a liquid, and that mineral-

particles are not subject to the full force of a rising current of water, but that the material is sifted down through the interstitial spaces of the bedding. Possibly another cause is at work, as noted in the behavior of the bed during the long strokes. Here the top of the bed pulsated for a longer time, and had a longer amplitude of vibration, and therefore the grains on the bottom came to rest sooner than those above, which would tend to limit the size of the particles passing into the hutch; and the longer and slower the stroke above the limits which will move the grains, the more pronounced will this differential motion be, and with it the increased perfection of the classification that must take place.

Class III., Group 1. Sphalerite, 10 per cent. Here the lowest ratio is found in Test 50, with weak pulsion and strong suction. An examination of the weights and percentages of Tables IV. and V. shows, however, that only relatively small amounts of the finest sizes are secured; but material ot 0.69 mm. (on 40-mesh) is recovered to an amount equal to about 41 per cent., while material larger or smaller than this size is not materially increased. Test 48, under similar conditions, gives similar results. Both ot these tests indicate that strong suction, within the limits of this group, is not advantageous. Test 54, with the same ratio of pulsion and suction, but only one-half the intensity, gives a higher ratio ot concentration and a slightly better recovery in the finest sizes. Test 52, under analogous conditions, gives somewhat similar results, except material on 20-mesh (1.31 mm. mean diameter). Test 53, involute cam, with strong pulsion and weak suction, gives very good results. Test 55, eccentric, gives the best results of all. In this case, not only a high percentage of the finest sizes of fair mineral-content was obtained, but the coarse sizes also were well represented, containing a high percentage ot sphalerite, which accounts chiefly for the high ratio of concentration.

It may be said for this group that the eccentric easily yields the best results; that strong suction and weak pulsion give the lowest, and weak suction and strong pulsion an improved ratio of concentration.

Class III., Group 2. An inspection of the tests in this group shows that the lowest ratio of concentration is indicated by Test 50, an involute cam, with strong suction and weak pul-

sion, already considered in Class III., Group 1; and very near it is Test 51, a circular-arc cam, with strong pulsion and weak suction, resulting in the production of very small amounts of the finest sizes; but nearly 45 per cent. of material on the 40-mesh (0.69 mm. mean diameter). Tests 42, 44, and 49 give results in the final ratios that are close together, but differing in the details. Test 42, circular-arc cam, with moderate pulsion and strong suction, and Test 49, involute cam, with strong pulsion and weak suction, give practically the same final result; and Test 44, involute cam, with moderate pulsion and strong suction, similar results.

The two higher ratios are those of Test 46, eccentric, and Test 53, involute cam, with strong pulsion, but the lowest for the group, and less suction. An inspection of the records of the experiments shows that, with the relatively low pulsion-velocity used, these two tests yielded relatively less of the coarsest sizes, but increased amounts of the finest sizes.

The superiority of the eccentric over the other forms of stroke is at once evident. In the case of all styles of stroke, the same pulsion-velocity gives final results much the same.

Class III., Group 3. Of the four tests grouped here, three are almost identical—namely, Tests 44, 47, and 49; and of these three, two have already been considered in Class III., Group 2. Test 47, circular-arc cam, with strong pulsion and weak suction, and Test 49, also strong pulsion and weak suction, produce about the same results as very strong suction and weaker pulsion, but in which, however, the pulsion-velocity is about the same. This indicates that the velocity of pulsion is the principal determining factor.

Class III., Group 4. The two tests in this group are very closely related. It is evident that the proper velocity of pulsion has been passed. The records of the experiments show that, at these high velocities, the coarse sizes readily pass into the hutch, but at the same time the percentage of mineral is much decreased, and much of the fine material is lost.

An examination of the four groups indicates that in the fourth the maximum velocity of pulsion has been exceeded for good work, but in the other three groups the best velocity is not so clearly indicated. With the three eccentrics good ratios have been secured in each of the groups, and this is

also the most efficient of the three types of stroke. A high pulsion-velocity is very efficient in saving material that rests on 20- and 12-mesh (1.31 and 1.90 mm. mean diameter of grain), but on sizes smaller than these less so than decreased velocities. A high suction-velocity is not generally more efficient in recovering the finest sizes than a more moderate one.

Class IV., Group 1. Sphalerite, 20 per cent. A comparison with the corresponding group of Class II. shows many features in common. The lowest ratio of concentration is found in Test 70, and next to it Test 68, both weak pulsion and strong suction. Test 72, the reciprocal of Test 68, gives better results. Tests 73 and 74, reciprocals of each other, indicate that between these velocities the involute cam is very efficient. Test 74, with strong suction, gives the highest ratio of the group.

Class IV., Group 2. Some differences as compared with the corresponding group of Class I. are found here. The minimum ratio of concentration is marked by Test 64, involute cam, with moderate pulsion and strong suction. Tests 62, 70 and 71—62 and 70, circular-arc cams and involute, respectively, with weak pulsion and strong suction, and Test 71, with strong pulsion and weak suction—give results that do not differ materially, indicating once more that even though the suction-velocity differs widely, the final results will not differ widely if the pulsion-velocities are close together. The eccentric, Test 66, shows a good ratio. Test 73, an involute cam, with stronger pulsion than suction, gives the maximum ratio for the group.

Class IV., Group 3. The four tests in this group give results agreeing very closely with the corresponding group of Class I., and the observations made under that group apply here.

Class IV., Group 4. A glance shows at once that this group agrees exactly with the corresponding group under Class I.

An examination of the four groups of Class II. indicates that in the first, with a pulsion-velocity not exceeding 2 in. (50.8 mm.) per sec., the highest ratios are obtained, and that at these velocities by far the largest percentage of the mineral recovered has a mean diameter of 0.69 mm. (through 20-mesh.). As the velocity is increased, more of the coarse sizes appear and less fine material.

For both Classes III. and IV., with sphalerite and quartz, it appears that generally a stronger pulsion-velocity than suction is more efficient in producing a better concentrate, and effects an equally good saving of the fines. The eccentric, between wide velocity-limits, is an efficient type of stroke. Of the two types of cams, the involute is generally the best. An examination of the tests will show that certain types and velocities of strokes are especially suited to the recovery of particles of fixed diameters.

V. Discussion of Pulsion and Suction.

Since the pulsion- and suction-velocity, as measured by the piston-speed, have been the chief variables in this investigation, the question naturally arises: can the exact rôle of each be definitely defined?

The accepted meaning of the terms "pulsion" and "suction" is doubtless familiar to all. A pulsion-current is one acting opposite to gravity, and tending to raise the grain off the jig-sieve; and a suction-current is one acting in the direction of gravity and supplementing it. In both cases, therefore, are reactions caused by the movement of a column of water or other liquid relative to some solid.

When the results of a series of tests are arranged according to the pulsion-velocity in the free part of the jig-column, or, in other words, the piston-speed, even though the suction-velocity differed widely, the final results are quite close together, indicating that the reactions occurring during this cycle determine the final result. With a perfect-fitting piston, given the areas of piston and jig-sieve, length and number of strokes per unit of time, the mean pulsion-velocity in the free or unoccupied section of the jig-column may be accurately determined; and similarly for the suction-velocity.

It has been demonstrated that under the reaction of pulsion with mixed sizes of grains of different specific gravities certain definite positions are established according to diameters. Thus, in the case of quartz and galena, the grain of quartz in equilibrium with a particle of galena was 5.8 times the diameter of the galena grain.

Stated in other words, the results of the pulsion-jig experiments indicate that in order to effect a perfect separation by

pulsion alone, the grains should be sized between the limits of these ratios, which may be distinguished from those of "free-settling ratios" by "interstitial equilibrium factors," or "hindered-settling ratios or factors." It is important to note that they are larger than those obtained by Rittinger's well-known formula. This formula states that in the case of a sphere the uniform velocity under "free-falling" conditions is:

$$v = 5.11 \sqrt{d\,(x - 1.0)}$$

in which,

v = Velocity of fall in meters per second.
d = Diameter of sphere in meters.
x = Specific gravity of sphere.
1 = Specific gravity of liquid (unity in case of water).

Thus, in the case of quartz and galena, if for x the specific gravities of the two minerals are substituted, equating and solving for the respective diameters, a ratio of about 4 to 1 is obtained. It is evident that the reactions occurring during pulsion have resulted in increasing materially the ratios possible under "free-settling" conditions. It seems to me that part of this increase may be accounted for according to Professor Munroe's[10] grain of maximum falling-velocity. He has shown that in a tube the grain of maximum falling-velocity is one having a diameter 0.4 that of the tube. Under the force of pulsion the interstitial channels are constantly undergoing a change in their diameters. A small grain of heavy mineral surrounded by the larger grains of lighter mineral will have frequent opportunities for occupying a channel about 2.5 times its own diameter. No doubt the greater acceleration of the small particle over that of the large one will always aid the separation, as pointed out by Rittinger.

It is evident that the experimental interstitial-factors or ratios obtained in the pulsion-jig are much smaller than called for by Munroe's theory,[11] where, in the case of above minerals, large grains closely surrounded by smaller ones, he obtains a ratio of about 31 to 1 for equal-falling grains.

Whatever may be the theoretical diameter-ratios between two minerals under pulsion, it is an easy matter, as pointed out by Professor Richards,[12] to determine what it is under practical conditions, and the ratios that exist under these conditions on a jig-bed are the ones that most closely concern the mill-man.

[10] *Trans.*, xvii., 645 (1888–9).
[11] *Trans.*, xvii., 650 (1888–9).
[12] *Trans.*, xxiv., 484 (1894).

As a resultant of all the forces acting upon the grains during the pulsion-cycle, a certain definite and distinct separation takes place according to the diameter-ratios of the two minerals. When this point has been reached, further separation, or an increase in the diameter-ratios, is not possible. In order now to remove the small grain of heavy mineral from the large grains of light mineral associated with it, the application of some other reaction is necessary. This force is suction, or, perhaps more properly, the reactions that occur during the suction-cycle.

Under the conditions that exist in a jig-bed, we are dealing with a number of columns of water moving with some velocity relative to the grain. The forces acting upon the grain will be those of the water-currents, of gravity, and of the resistance opposed by the walls of the channel or other grains. The effect of the water-current alone upon the grains may be considered a purely non-selective force. For grains of the same size and shape a given current will exert as much effort upon a particle of galena as upon one of quartz. Any advantage that the small heavy grain has over its larger companion, due to acceleration, will always be a positive force. The resistance offered to the passage of the grain by other surrounding grains will depend upon the relative diameter of the channel and the grain, and the length, shape, and inclination of the channel. If the grains are all the same size and shape, then the mean diameter of the channels will be less than the diameter of any of the grains, and none of them could be carried through the interstitial spaces. Take as an extreme case a column of shot, steel balls, or marbles of the same diameter, they are all absolutely fixed as regards any possible suction-velocity. The same is true, through to a less extent, in rounded particles not all the same size, as well-worn sand, gravel, etc. Again, the possibility of the mass becoming packed is small. Of course, the reason for this is well understood, and is owing to the fact that in these cases the surfaces of the particles are curved, and therefore the points in contact are reduced to a minimum. Under any practical conditions existing in the jig-bed, the particles are not all the same shape or size, and instead of being bounded by curved surfaces they are angular and bounded by planes. This results in neighboring grains having not few but many points in contact, accompanied always by a more or less

wedging action, and therefore jigging under excessive suction-velocity results in a tight bed. The wider the size-ratio the greater the effect, and *vice versâ*. The possibility of applying suction depends upon the ability to maintain within the jig-bed interstitial channels somewhat larger than the maximum grain to be saved. Under the conditions existing on a jig-bed, the effect of increasing the diameter-ratio of bedding and feed, the number of bedding-grains in a vertical column, or thickness of bed, and the character of the bedding-grains themselves, whether they are rough and angular, cubical, or well worn and spherical, is at once evident.

The increased catch secured on a jig-bed over that obtainable by rising current alone, under either free or hindered settling conditions, is due to the reaction occurring during suction. In order that suction may become effective, it is necessary that the reaction of pulsion precede. During pulsion a selection and arrangement takes place; and during suction a destruction of the conditions of equilibrium set up under pulsion, by the removal of the small heavy grain through the interstitial channels into the hutch, results. Suction always supplements gravity, but in a way in which gravity cannot act efficiently—that is, in the movement of grains in channels more or less inclined or crooked, where a particle could easily lodge, although large enough for the grain to move in if vertical. The current moving with high velocity in these spaces serves to move the particle. Pulsion may be said to be the master reaction, while suction is its necessary complement, completing what has been initiated by pulsion. Suction is therefore necessary in jigging all unsized material. Excessive suction with sized material, under practical conditions, would be disadvantageous. With very close sizing on coarse jigs it would not be particularly harmful, but it would be useless. In jigging under any conditions, more or less suction will be of advantage, as helping to save the smaller particles of heavy mineral that otherwise might be carried off with the tailings.

VI. Discussion of Acceleration.

It has been pointed out (Tests 16, 17, 18, 37) that with a very short and quick stroke, but relatively low piston-speed, the ratio of concentration obtained was low. Moreover, the

jig-bed pulsated under the influence of the short, rapid stroke, and did not with the longer one of less frequency, but having the same mean piston-speed in inches or millimeters per sec. This was a movement of the grains *en masse*, the bottom pulsating quite as much as the top, and was altogether different from that gentle, selective action observed with proper speeds and frequencies. The jig-bed moved as it would if acted on by a solid piston from below. Thus, by giving many quick sharp blows to the jig-bed, the water-columns have not time to adjust themselves to the increased pressures, except by raising the grain which happens to be in the direction of impulse. In addition to the mean piston-speeds, as derived from Professor Munroe's formula,[13] the element of time during which the impulse lasts should be included. This solid or piston-effect of a water-column can, perhaps, never be entirely eliminated, nor does it seem desirable that it should be. The results show that increased quantities of hutch-work are produced, supplementing suction by keeping the interstitial channels cleared. Since the grains on the bottom are the first to feel the impulse and be raised, it has been shown that true pulsion is diminished, and the important reactions dependent on it diminished. Sharp, rapid strokes, by increasing the piston-effect, promote sifting, and therefore aid suction, but decrease the reaction of pulsion.

VII. Résumé and Conclusions.

Referring to the 13 conclusions of Professor Munroe, quoted in the early part of this paper, it may be said that no experiments have been carried out with the idea of duplicating the work covered by the first six of his conclusions. In the absence of positive experimental data, it may be considered quite out of place to enter into a discussion of them. However, in the light of results of the present investigation, a few observations concerning these first six conclusions may be given. The careful record of so many tests, under the conditions observed by Professor Munroe, seems to cover the field thoroughly.

Conclusions 1, 2, and 3 are undoubtedly fundamental propositions in any system of jigging. To Professor Munroe is due the credit of having first clearly pointed these out and applying

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[13] *Trans.*, xvii., 647, 648 (1888–9).

them to jigging. Following, as corollaries, are the formulas given for the velocity of fall of grains *en masse.* The formulas for the falling-velocities of grains *en masse* under the assumed conditions, when applied to piston-speed, have been demonstrated by experiments with the pulsion-jig, the Vezin jig, and the Harz jig yield satisfactory results.

Conclusion 4 has been noted elsewhere. A grain 0.4 the diameter of the channel will have a maximum falling-velocity, which therefore increases its chance of being saved, and of increasing the interstitial settling-ratio.

Conclusion 5, in the first part, follows, also, from the first three conclusions, and its application fully demonstrated by Professor Munroe. It seems to me that there is a reasonable doubt about accepting the second part of this conclusion. There is no doubt about this part of it: "The falling-velocity . . . [of a mass of grains] increases or diminishes with the distance apart of the grains," since this is merely a re-statement of Conclusions 1, 2, 3, and 5. When, however, the balance of this statement is examined—that is, ". . . the velocity of the current necessary to support or raise the mass of grains increases or diminishes with the distance apart of the grains," I believe we are entitled to withhold judgment until it has been shown what these velocities, under the conditions of jigging, actually are. This statement is true if we assume that the velocities supporting or raising the grain are equal to the observed velocities in the free or unobstructed part of the tube; or in practice the piston-speed. But are these the velocities acting upon the grains? Under the conditions obtaining on a jig-bed, the grains occupy a considerable area, and therefore constrict the passage. It is a matter of actual observation that the velocity in the interstitial spaces is much higher than that of the jig-piston. It is the same principle of conducting a given volume of water through a pipe-line made up of, say, a 12-in. and a 6-in. pipe. In the 12-in. pipe the column of water will have a mean velocity of x feet per sec., and in the 6-in. section the velocity has been increased to 4 x. Thus, we must be careful not to confuse the falling-velocity of grains *en masse* with the velocity of the water-column actually supporting them during pulsion.

It has been noted by Professor Munroe that spheres falling in tubes have a maximum falling-velocity when the diameter

of the sphere is 0.4 that of the tube; and spheres either smaller or larger than this size fall with less velocity. If the column of water in the tube has a velocity of 0, or is at rest, a solid falling through this water-column will displace a volume of water equal to its own volume as often as it traverses a distance equal to one of its three dimensions. This displaced volume must escape within the interstitial space of tube and body with some velocity, depending on the velocity of the falling body and the ratio of the diameters of the falling body and the tube. If the falling body has a diameter nearly equal to that of the tube, the area of the interstitial space is small, and a low falling-velocity of the body may correspond to a high interstitial velocity of the water-current. Thus, while the velocity of fall decreases as the diameter of the solid approaches that of the tube, at the same time the velocity of the current tending to support it increases. If the body has a diameter equal to that of the tube, any motion of the solid would mean an infinite velocity to the interstitial current, and the body stops. On the other hand, as the diameter-ratio between the solid and the tube increases, the area of the interstitial space increases, and the volume of displaced water decreases, and with it the interstitial velocity, and the body would tend to fall with a high velocity; but the force causing it to fall, its weight, is also smaller, and therefore its ability to overcome the inertia of the liquid, and other resistances, is less, so that its falling-velocity is less. The possibility of interstitial currents depends upon a solid of any diameter less than the tube, and having a specific gravity greater than that of the liquid, and which is free to fall, or resists the motion of a column of the liquid in which it is immersed.

It is evident that if a velocity be given to the water-column in the free part of the tube equal to the observed velocity of fall of the body in the stationary column, then the body will be supported or remain at rest. This velocity of the water in the column is the apparent velocity necessary to support the grain, and some function of the actual velocities supporting it. In jigging, it is not so much the velocity of fall of a mass of grains that concerns us, as the velocity of the current necessary to raise or support them. In jigging, the grains are not free to fall, since they are firmly supported on a sieve, but they are

quite free to move when the interstitial currents are acting in pulsion. When the force due to the velocity of the rising currents is greater than all other forces holding the body at rest, then the body moves in the direction of the greatest forces, and continues its motion so long as the forces are unbalanced. Thus, it has been observed that the particles will be raised to positions higher than at rest during the action of the pulsion-current. The grains in the bed are being raised because each one in motion is seeking a position higher up in the column where the distance between grains is greater, or, in other words, where the interstitial velocity is lower.

Conclusion 6 admits of no doubt.

Conclusion 7 is an axiom as regards the first part. The second part concerns the ratio of equal-falling particles of the pair chosen—namely, quartz and galena. No ratios were obtained in any of the investigations approaching those called for by this theory. Evidently the conditions required by the theory were not present. The conditions assumed were that the fine grains should closely surround the large grain of quartz. It has been observed in all experiments that the large grains quickly settled on the bottom—the smaller and lighter above, whether of bedding or ore. This fact was also pointed out by Professor Munroe in his paper on his experiments with mixed shot.[14] There is but one force that can carry the small, light grain to the top. That force resides in the velocity of the interstitial currents acting during pulsion. Certainly, in the pulsion-jig experiments, where the unsized material was thoroughly mixed, and added practically dry in order to avoid any classification in falling through a water-column, and where very large percentages of the heavy mineral (over 70 per cent.) were used, the above ratios should have been secured. In the case of the above pair it was found that a particle of galena and one of quartz 5.8 times its diameter were in equilibrium. If the conditions called for by the theory were present, and the results not fulfilled, then an examination of the theory is in order. But we have observed above that while the material was thoroughly mixed when added to the tube, the fine, light grains immediately separated from the large, heavy

[14] *Trans.*, xvii., 649 (1888–9).

ones during the first few strokes of pulsion. From this we must conclude that the fine, light grains were not in equilibrium with the large neighbors, and sought positions higher up in the column where they were. When this was found they remained fixed, or were in equilibrium. These ratios have been given elsewhere. For quartz and galena the ratio was 5.8 to 1.

The conditions assumed cannot, under any possible conditions, exist on the jig-bed, and therefore the results that would follow cannot possibly be attained in practice. The conditions would be fulfilled if we caged all the light and heavy grains, and prevented any movement among them; but this is the very condition that we do not want on a jig-bed. It is hardly fair to assume that if in one way or other we are able to keep a mass of mixed grains together, under conditions where the small fellows cannot escape, therefore the small grain is falling with the same velocity as the large grain. It is in equilibrium by force, not choice; and on the jig-bed we try, as far as possible, to encourage the grains to exercise the latter and not the former.

Possibly if formulas had been derived showing the velocity of the interstitial currents (the currents supporting or raising the grain), and from these, equal-settling ratios were derived, the values would be much less than 31 to 1, and probably close to those obtained in the pulsion-jig.

Conclusion 8 follows from the conclusions 1, 2, 3 and the first part of 5. I can bear testimony as to the practical accuracy of this, since I have calculated many a piston-speed and velocity in the free tube in the pulsion-jig. With the formulas given, it has been shown that with pulsion-jigs, Vezin jigs, Harz jigs, etc., the piston-velocity so calculated suffices to move the grains. Given the size or diameter, and the specific gravity of the minerals to be separated, the jig-piston velocity may be calculated with almost a nicety. It has been shown in the experiments in piston-velocity that a considerable variation is permissible in jigging.

Conclusion 9, the first part of Conclusion 11 and all of 13 are corollaries of the last part of Conclusion 7. Since the conditions assumed for Conclusion 7 cannot exist on a jig-bed, therefore no support is left for 11 and 13, and some other ex-

planation must be given to account for the applicability of the English system. This action has been discussed under pulsion and suction.

Conclusion 10 has been abundantly demonstrated. It might be added that if the theory were applicable little or no suction would be necessary.

Conclusion 11. The last part of this conclusion, concerning the presence of more or less coarse material in jigging very fine material, agrees with practice, since, if not in the feed, a bed is used, which fulfills the conditions. The tests do not cover cases in which any large percentage of feed was less than 0.10 millimeter.

Conclusion 12 accords with all results of practice and experiment, and is therefore another fundamental proposition in jigging.

Finally, to Professor Munroe must be given the credit for having pointed out the fact that bodies fall with less velocity in tubes than in large bodies of water, and for having demonstrated the applicability of formulas based on this fact to obtain correct jig-piston velocities under the assumed conditions. It is to be always understood throughout this paper, that under records of the experiments, where pulsion-velocity and suction-velocity are given, the value expressed in inches or millimeters per second is that of the piston or the water-column in the free or unobstructed part of the jig only, and clearly not the actual pulsion-velocity acting upon the grains during these reactions. One is a function of the other, but under the very conditions obtaining on a jig they cannot be equal.

Comparing the results given by Professor Richards, a part of whose conclusions are quoted earlier in this paper, it will be found that, so far as the experiments may be compared, there is a very close agreement between us. Since we both started from the same experimental basis, on which we were agreed, it is but natural that our conclusions should be in close harmony. This theorem, which forms the basis in every practice of jigging, is all important, and of course is the establishment of the value of the resultant measured by the diameter of grains differing in specific gravity obtained during pulsion alone. This factor represents all that can possibly be expected from every force acting upon the grains of a jig-bed during the time the pulsion-

currents are acting, or while the grains are free to fall. To Professor Richards is due the credit of having demonstrated the value of this resultant as measured by the ratios of diameters. My own researches, carried out in a different manner (see pulsion-experiments), have abundantly confirmed the substantial accuracy of these ratios. When, therefore, Professor Richards says: "The two chief reactions of jigging are pulsion and suction," I see no escape from them. If we go a little further and say: "The reactions occurring during pulsion and suction are the only reactions of jigging," we have included every force imaginable that can act upon the grains. As pointed out above, the resultant of all the forces acting upon the grains during pulsion is given by the interstitial or hindered-settling ratios as determined by Richards and myself. The resultant of suction cannot be separately determined, apart from that of pulsion. There is no determinable resultant of suction as measured by a ratio or factor.

Summarizing some of the principal points brought out in this investigation, I believe the following may safely be accepted:

(1) The pulsion-reaction is by far the most important one in the process of jigging. During this period, with sized grains of different specific gravities, with proper pulsion-velocity, the separation between them will be complete. The size-limit is indicated by the hindered-settling ratio. If the minerals are not sized, or above these ratios, the separation cannot be complete, but a definite arrangement will result. The positions of equilibrium will be attained when the above ratios of diameters are attained, after which further separation by pulsion is impossible.

(2) Suction due to the movement of water-columns supplements gravity. Resisting the sum of these two forces is the resistance of the walls of the tube through which the grain must pass. The reaction, as a whole, must therefore be a resultant. The chief components are the force of the water-columns, which are purely non-selective, but act with equal intensity upon all particles of the same shape and size, regardless of their specific gravity or weight. Any advantage that the small heavy grain would have over a large light one would, of course, appear in the resultant tending to carry it to the hutch. The effect of the forces opposing the movement of the grain depends upon

the character of the grain, and the conduit through which it is supposed to pass. Under any condition, the diameter of the grain cannot be greater than that of the conduit. If the channels are inclined, or crooked and zigzag (the condition obtaining on a jig-bed), the particles will more easily lodge against the sides of a tube large enough to pass through if the tube were vertical, but under the force of gravity they remain at rest. The rapidly descending water-currents passing through these channels easily carry the grains along. Thus suction, due only to the moving columns of water, constitutes a powerful impelling force to carry through the interstitial spaces those particles which under the force of gravity alone cannot move. Suction is, therefore, a necessary complement to pulsion in the jigging of all unsized material, and generally valuable in jigging under all conditions.

(3) From the observations under (2) it is clear what effect the bedding will have upon the result. Any part of the bedding or ore-column remaining fixed during the pulsion-cycle must be looked upon merely as a mass of very irregular tubes, of length somewhat greater than the thickness of such part, owing to their inclination, since they are mostly inclined. To that extent they are only an extension of the jig-sieve. The result of thickening or thinning the bed, or of increasing or decreasing the size-ratio between bedding and feed, is evident. This assumes, of course, that the largest particle of feed is smaller than the sieve-aperture, and always the bedding-grain must be larger than the sieve-aperture. It is evident, too, that the shape of the bedding-grain will have a marked effect. Grains that are more or less equi-dimensional, as galena, etc., will form a more open bed than one of antimony, which breaks into long pencil-shaped grains. Finally, of course, if the bedding is in use long enough all grains become worn and spheroidal. Any part of the bedding free to pulsate is to be considered as part of the ore-column, and is amenable to all the conditions applying to this reaction.

(4) The effect of very rapid acceleration, amounting to a shock or blow to the bottom of the jig-bed, is an important factor. Its effect is to accelerate the work done by suction, and render a larger catch possible with a low mean piston-velocity. The pulsation of the jig-bed due to this force and

that taking place under the regular interstitial velocity should be distinguished. One sifts, the other separates.

(5) The results of the many experiments, in which the piston-speeds during the pulsion and suction were not the same, seemed to show that only by properly balancing the two are the best results attained. It has been generally noted that the eccentric, giving equal mean velocities, yields about as good results as any of the accelerated strokes. This observation applies only for the size-ratio used in the tests, and it is not safe to speculate what the results would be for other sizes.

(6) While the use of the jig for the treatment of material sized between wide limits is possible and practicable, still the advantages that are bound to follow where a more or less perfect sizing has preceded cannot be denied. It must be observed, that in the English system itself, when the hutch-products of one jig are treated on another we are using sizing.

(7) The more general application of the English system, or the use of the jig in the treatment of unsized material instead of the hydraulic classifier, seems to be clearly indicated. This has been recognized in some quarters, but a wider use than has hitherto been accorded it appears to hold out favorable inducements. This seems to be a field eminently suited for the English methods of jigging—one that is not and cannot be filled by the Continental system.

(8) The arguments that have been advanced for the adoption of the English system on the ground that equal-settling ratios, many times larger than those obtainable under free-settling conditions, exist on the jig-bed, are not tenable. These hypothetical ratios cannot possibly exist on a jig-bed.

In conclusion, I must acknowledge the great help and many suggestions derived from the works of Professor Richards and Professor Munroe; to the latter personally, I owe cordial thanks for numerous timely suggestions. I have also had the benefit of his valuable criticism in the construction of the laboratory-jig, with which many of the experiments were made.